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NAVORD REPORT

4236

AD No 116878

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**THE DEVELOPMENT OF IMPACT SENSITIVITY TESTS
AT THE EXPLOSIVES RESEARCH LABORATORY
BRUCETON, PENNSYLVANIA DURING THE YEARS
1941-1945**

FC

16 MARCH 1956



**U. S. NAVAL ORDNANCE LABORATORY
WHITE OAK, MARYLAND**

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NAVORD Report 4236

THE DEVELOPMENT OF IMPACT SENSITIVITY TESTS
AT THE EXPLOSIVES RESEARCH LABORATORY
BRUCETON, PENNSYLVANIA DURING THE YEARS
1941-1945

Edited by:
H. Dean Mallory

Approved by: E. C. Noonan
Chief, Fuels and Propellants Division

ABSTRACT: This NAVORD Report consists of reproductions of reports which are no longer generally available. They report work carried out in 1942-45 at the Explosives Research Laboratory, Bruceton, Pa. The Bruceton Impact Machine (now used at the Naval Ordnance Laboratory) is described, and the development work with it is fully reported. It is as a result of this investigation of 14 different tool types (hammer and anvil combinations) and of other variables affecting the test value that the present NOL standardized impact sensitivity test for high explosives was selected.

Most of the ERL work was carried out by Rogers F. Davis whose progress reports are the major portion of this NAVORD Report. Summary reports of his work have appeared in OSRD reports 804 (1942) and 5744 (1945). The first of these is also reproduced in this report.

Explosives Research Department
U. S. NAVAL ORDNANCE LABORATORY
White Oak, Silver Spring, Maryland

5611

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NAVORD Report 4236

16 March 1956

The interest shown in impact sensitivity testing at the Naval Ordnance Laboratory conference on Explosive Sensitivity, 28-29 June 1955, pointed to the need for information on this test method. The present report represents the whole of the ERL data available to Naval Ordnance Laboratory workers. The complete reports have not previously been available to others.

This information is issued under Task NO 301-664/43006/12040. The report is for information only and is not intended as a basis for official action.

W. W. WILBOURNE

Paul M. Fye

PAUL M. FYE

By direction

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THE DEVELOPMENT OF IMPACT SENSITIVITY TESTS
AT THE EXPLOSIVES RESEARCH LABORATORY
BRUCETON, PENNSYLVANIA DURING THE YEARS
1941-1945

Introduction

During World War II, interest in explosives research was stimulated and much was accomplished. The aspect of the subject related to the ease of initiation and propagation was dealt with by a number of groups but principally those associated with Bowden and Ubbelohde in the United Kingdom. Their results have been published both in the classified and open literature. Professor Bowden and his co-workers have published extensively in the Proceedings of the Royal Society, and in addition the monograph by Bowden and Yoffe, Initiation and Growth of Explosion has been widely read. Professor Ubbelohde and his co-workers have published their collected works in Phil. Trans., A241, 197-296 (1948). Impact testing has been an important phase of the British work.

A large part of the United States' Impact Sensitivity work, especially the development of methods, was done at the Explosives Research Laboratory, Bruceton, Pennsylvania during the period 1941-1945. Results of the work were published as OSRD Report 804 (1942) and OSRD Report 5744 (1945). The first of these is in the form of a brief progress report (which is included in the present collected report) while the second is a summary of the findings which includes a short description of each tool type and some of the results obtained.

Data from most impact machines will, in a general way, be found to match the sensitivity orders as determined by one of the ERL tool types. It is hoped that information such as this will be an aid in the understanding of impact data. By following the step by step progress made during the evolution of the various tools, some groups may decide their tests can be improved upon by adapting a different tool design to their available machine.

With the exception of the first few pages which are from OSRD 804, the present report is made up of detailed progress reports by Rogers F. Davis to Dr. E.H. Eyster at the ERL, Bruceton, Pa. The original editions were limited to about five copies of each. It is

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therefore obvious why most persons engaged in impact testing are not acquainted with them although they have probably read the two OSRD Reports. 804 and 5744.

Although it might have been possible to reissue the two OSRD Reports instead of the present detailed material, it was felt important that all the information be made available especially now that further attempts are being made to understand the mechanisms of initiation. It seems reasonable to suppose that the hot spot idea, as suggested by Ubbelohde and developed by Bowden, can now be extended by considering the effects of heating times. It is not too difficult to detect the time element, in a rough fashion, in Davis' data as tools are used which have various degrees of confinement; the hot spot temperatures reported by Bowden may in this way be somewhat dependent on tool type.

This collected report has been made up from the following:

1. OSRD 804 (the impact part covering work up to July 1942)
2. The Behavior of Explosives to Mechanical Shock (covering the period August 1942 through June 1944)
3. The Behavior of Explosives to Mechanical Shock as Studied by Bruceton Impact Test No. 12 (covering the period August 1943 through July 1944)
4. Concluding Report of the Problem of the Behavior of Explosives to Impact (dated October 1945)

The reports have been kept in the above sequence to make it easier to follow the chronological development of the work.

A uniform page numbering has been adopted throughout this report. Every page carries a Roman numeral referring to the number of the original Bruceton report, followed by a number designating the page within that particular report (I-1-13; II-1-108; III-1-51; IV-1-29). Immediately below is the page number of the collected report (1-200).

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Report I (from OSRD 804)

Direct Impact Tests

The work described in this section has been performed by Mr. H. Knudsen, Dr. C. H. Sage, Dr. E. H. Eyster, and Mr. Rogers Davis.

Of the three impact machines of the Bureau of Mines only the so-called small one has been found suitable for general testing work on military explosives. It is described in the Bureau bulletin No. 346, but certain modifications have been introduced for the purposes of this work. Thus the heavy striker of the original machine has been replaced by a small steel rod, 2 inches long and 1/2 inch in diameter made of a high-grade alloy steel (Ketos steel) properly hardened by heat treatment.

HARDENING PROCEDURE FOR KETOS ANVILS AND STRIKERS

Put piece to be hardened in furnace when temperature reaches 680°C. Raise temperature quickly and hold constant for fifteen minutes as follows:

	<u>1/2 inch piece</u>	<u>1 1/4 inch piece</u>
Ketos Steel	800°C	815°C

Quench in water-free oil until cool enough to hold in hand. Then transfer immediately to a tempering oil bath for two to three hours. Temperature held at 230°C.

Ketos steel is obtained from the Crucible Steel Company.

The anvil has been made in the form of a rod of the same steel, 1 1/4 inch in diameter and from 1 to 1 1/2 inch long depending on the type of holder used. Both are mounted in a steel frame (See Figure 1),* which is readily removed from the machine for interchange of damaged parts. The striker slides in a vertical sleeve opposite the center of and perpendicular to the top surface of the anvil; the latter is firmly held in the frame and rests directly on the heavy base plate of the machine. The 2 kg. weight of the original machine has been replaced by a 5 kg. weight for the majority of tests.

*Figure 1 not available in original I-1b report.

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A second machine has been built, using the same striker-anvil unit but embodying several changes in the mechanical details of construction. The most important one of these is a mechanical release of the weight, rather than a magnetic one. Actual experience has shown, however, that the magnetic device is really preferable, as giving a more reproducible trajectory of fall of the weight. This second machine has been provided with a device to prevent rebound. The observation of detonation on impact is auditory on both machines. With some explosives, particularly the less sensitive ones, only partial detonations are usually observed, which are sometimes difficult to classify; this, however, is only one of the lesser difficulties of these tests.

In accord with other reports on the subject, the work with these machines soon showed that the precise form and nature of the striking surfaces, as well as the manner of distribution of the explosive and its form have profound effects on the results of the tests.

Experiments have been made with a considerable number of differently fashioned strikers and anvils, but most of these have been found impracticable because of a variety of reasons. The chief of them were that: a) the metal parts did not stand up well under the punishment, giving irreproducible results; b) the relative sensitivities of the known explosives did not fall into a series commonly accepted, the duplication of which seemed to be desirable, and c) the designs were too "insensitive" i.e., only very sensitive compounds could be fired with the maximum available energy, 5 kg. weight from 100 cm. height.

Extended series of trials have been made with the following designs of the striker-anvil combination:

- 1) A flat-ended striker of 1/2 inch diameter on a flat anvil.
- 2) Same design as No. 3, but the flat anvil is replaced by a truncated cone, the flat top area facing the center of the cap being 1/4 inch in diameter.
- 3) A flat-ended striker turned down at its lower end to 0.306 inch diameter, over which slips a brass cap (standard percussion caps, obtained from the Western Cartridge Company, East Alton, Illinois) of 0.310 inch internal diameter and about 1/8 inch high. The

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anvil is flat and the explosive is placed in the cap.

4) The striker has a flat bottom $3/8$ inch in diameter with a bevel $3/64$ inch wide ground around the edge at such an angle that good contact is made with the surface of a spherical depression ground out in the anvil on a $1/2$ inch radius.

5) The striker is flat ended and fits snugly into a flat-bottomed depression in the face of the anvil, $1/16$ inch deep and $3/8$ inch in diameter. The explosive is placed in this depression and covered by a layer of tin foil. The striker is then pressed into the depression so that the foil acts as a gas seal around the edges.

6) Same design as No. 2, but a spherical depression $3/16$ inch in diameter is ground out on the top face of the anvil on a $1/4$ inch radius.

With all designs it is essential to use a standardized quantity of the explosive, the striker must be pressed by hand onto the sample before dropping the weight and the parts must be washed with a suitable solvent after each trial. Even though all efforts are made to standardize the parts and their heat treatment, it is not always possible to duplicate the data of one particular set of parts with the next one, seemingly identical. Less satisfactory designs among those enumerated above, give heights for 50% explosions which vary by as much as a factor of two from one set of parts to another. Furthermore, the same set of parts shows changes in results due to progressive wear, although such changes are frequently not pronounced. Nonetheless it has been found essential to make tests on standard substances at very frequent intervals. This, naturally, delays the progress of the tests and hence a relatively small number of trials is now made on each material. What is lost thereby in statistical accuracy of the result, is gained through better preservation of parts for the next series of trials with a standard substance. Unless the parts show obvious signs of wear and of irreproducible behavior, the presently accepted test includes but twenty trials on the new material, followed by an equal number on a standard.

The materials are measured out for the trials not by weight but by means of a small spoon holding about 20 mm^3 of the explosive. This procedure is faster and yet does not impair the results significantly.

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All materials are carefully dried before trials but otherwise most new materials go into the tests as received. Afterwards they are remeasured after grinding and sieving, only the fraction passing No. 100 and retained on No. 200 being used. All standards are used after similar sieving.

With mixtures, particularly including substances of greatly differing sensitivities, sieving must be avoided to prevent segregation. Milled mixtures, particularly those including waxy substances, are not subjected to further grinding to avoid changes in the state of phlegmatization. Cast mixtures also often give quite different sensitivities from those of a simple mechanical mixture of the same ingredients. The procedure has therefore been developed of casting very thin wafers of such mixtures between glass plates, stripping them, cutting to size, inserting into the brass caps of Nos. 2, 3, or 6 design, and cautiously fusing again on the bottom of the cap by heating.

The operational procedure is as follows: a trial is made at some arbitrary height of fall and for the next trial either the next lower or the next higher height is chosen, depending upon whether explosion did or did not take place. This is continued until the test is completed. Trials are made at intervals of 1 cm. or more, depending on the total height. The trials are continued until sufficient data have been accumulated and then a standard is run in the same manner.

Table I shows a typical set of trials, capital E's indicating explosions, capital N's absence of same. All partial audible explosions are counted as E's but a mere visual charring of parts of the charge is considered to be an N. In calculating the height of fall which gives 50% explosions, it is assumed that: a) if, in a trial from a given height, explosion occurs, explosion would have occurred in this trial from any greater height; b) if, in a trial from a given height, no explosion occurs no explosion would have occurred in this trial from any lower height. To express these assumptions, lower case n's are written in Table I below each capital N and lower case e's are written above each E. To calculate the percentage explosions for each height, one takes the sum of all N, n, E, e for this height and divides by this the sum of E and e, thus:

$$\text{percentage explosions} = \frac{\sum E + \sum e}{\sum E + \sum e + \sum N + \sum n} \times 100$$

This procedure is a convenient and rapid one for determining the

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height for 50% explosions, if it is combined with the above described procedure for carrying out the trials. It should not be used with the more conventional procedure of making equal numbers of trials at preselected heights, as erroneous results will be obtained. It is also not correct for determining the height for any other percentage of explosions, except the 50% height. Finally, it must be noted, that, all data are discarded in the beginning of each series of trials until a break is reached, i.e., if at first explosions were obtained, the data are taken from the first trial without explosion and if the trials started with non-explosions, then the first valid result is an explosion obtained by successive raising of the height of fall.

TABLE I
A TYPICAL SET OF IMPACT TRIALS

Height of Wgt.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
60 cm	e	e			e	e	e				e			E	e		e	e		e
55 cm	E	e			E	e	e				E		N		E		E	e		e
50 cm		E		N		E	e			N		N	r			N		E		E
45 cm			N	n			E		N	n		n	n			n			N	
40 cm			n	n				N	n	n		n	n			n			n	
60 cm	$\frac{11}{11} = 100\%E$								50% pt. = 50 cm.											
55 cm	$\frac{10}{11} = 91\%E$																			
50 cm	$\frac{5}{10} = 50\%E$																			
45 cm	$\frac{1}{9} = 11\%E$																			
40 cm	$\frac{0}{9} = 0\%E$																			

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We shall now consider the different designs of the striking surfaces one by one.

Design No. 1

This design gives reproducible results on Cyclonite (23 cm.) and more sensitive materials, like PETN (15 cm.) etc., if the area of the explosive under the striker is controlled. TNT gives partial and only occasional detonations at heights of fall even as great as 300 cm. Even for Tetryl this design is unsuitable. The following Table II shows the percentages of explosions (calculated by the conventional procedure of making equal numbers of trials at preselected heights) as function of height, obtained for Tetryl. It will be observed that the percentage of explosions first increases with height of fall, but then decreases and does not reach 50% at any height tried. The explanation of this behaviour is found in the easy expulsion of the material from between the smooth steel surfaces of the striker and the anvil. Before enough energy has been supplied to particles of Tetryl to ignite them, they are scattered about. Only a small fraction of the initial sample is left under the striker and this is found in the form of an extremely thin, wax-like, non-crystalline layer, which is probably just as difficult to bring to detonation as is gelatinized nitrocellulose (compared with the fibrous material). The observed decrease of percentage explosions at greater heights is probably due to both causes; more complete ejection of the material and more complete "gelatinization" of the remaining fraction.

Very striking results are obtained by placing tin foil (0.0005 inch thick) on the anvil, then the sample, then foil again. The heights for more sensitive explosives are not greatly changed thereby but now Tetryl is found to be more sensitive than Cyclonite. (See Table III). This is a finding which, as will be seen later, is obtained with all designs providing large resistance to lateral motions of the explosive particles and placing the sample in a condition of "high confinement" as regards the freedom of escape of the products of explosion.

When a small depression is ground out in the anvil of No. 1, the height of fall for 50% detonation with Cyclonite is depressed to 7 cm. although neither Tetryl nor TNT can be located on the scale reaching up to 100 cm. Thus with such design we find conditions opposite to those obtained with tin foil.

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Design No. 3

This has recently been adopted as standard for explosives of equal or greater sensitivity than Tetryl. The advantages are a rapid execution of tests, good reproducibility and a "reasonable" sequence of sensitivities of the several common explosives tried. With heights of fall of more than about 70 cm. the striker deteriorates rapidly and yet TNT with this design is still above 100 cm. The excellent reproducibility is shown in Table IV which gives results of tests on a series of materials consisting of a rather insensitive crystalline filler with a resinous binder which increases the sensitivity.

The type 3 anvil and striker combination has now been in use long enough so that a critical study can be made, both of this particular device, and also of the operational procedure adopted for determining the 50% explosion points. During the recent intensive study of the sensitivities of cyclonites prepared by various means, a sample of cyclonite received from England has been used as a standard. We now have data on this material which include well over a thousand falls of the weight, and hence a reliable statistical treatment should be possible. Normally one run of twenty shots on the standard is made each day, and this summary includes results from fifty-four such runs, extending over a two and a half-month period, and no results have been discarded. During this time a large number of strikers and a smaller number of different anvils have been used.

Figure 2* is a plot of the per cent explosions obtained against the height of fall of the 5 kg. weight. Because of the procedure adopted, in which the height of fall is lowered or raised after each trial, depending upon whether an explosion is obtained or not, most of the trials are confined to a rather narrow region in the neighborhood of the fifty per cent point. For example, there were 353 trials at 50 cm., 251 trials at 55 cm., 252 trials at 45 cm., but only eighteen times was it necessary to go to a height of 65 cm., or one of 35 cm. From the graph it is seen that the 50% point is at 50 cm. (It should be pointed out that these results include only actual falls of the weight, and no "assumed" results are used, as is done in our standard method of treating the results.)

In order to give an idea of the reliability of our standard method of obtaining the sensitivity from a run of twenty shots (for want of a better name we shall refer to this as the "Bruceton method" to distinguish it from the conventional method) we give in Table V the values obtained for the fifty percent explosion points in each of the fifty-four runs of twenty shots each.

*Figure 2 not available in original report.

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TABLE II

HEIGHT VS. % EXPLOSIONS OF TETRYL ON NO. 1 DESIGN

Height, cm.	0	30	50	75
% Explosion	0	25	20	10

TABLE III

COMPARATIVE SENSITIVITIES WITH SOME OF THE
DESIGNS TRIED

Figures given give height in cm. for 50% explosions with a
5 kg. weight

<u>Design</u>	<u>COMPOUNDS</u>					
	<u>PETN</u>	<u>Cyclonite</u>	<u>Tetryl</u>	<u>P.A.</u>	<u>TNT</u>	<u>Trinitroanisole</u>
No. 1	15	23	>100		>100	
No. 1; tin foil	6	17	8		>100	
No. 3	20	50	47		>100	
No. 2		45	44		>100	
No. 2; tin foil		21	18		62	
No. 4	10	19	20	about 100	>100	
No. 5; tin foil	8	20	10		45	
No. 6		33			56	64

TABLE IV

EFFECT OF A BINDER ON 50% EXPLOSION HEIGHTS ON
NO. 3

% Binder	0	1	2	3	5	7	10	15
Height, cm.	88	27	23	18	17	14	13	10

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TABLE V
RELIABILITY OF THE BRUCETON
METHOD

<u>Fifty percent Explosion Height</u>	<u>No. of Times Obtained</u>
41 cm.	2
42 cm.	1
43 cm.	0
44 cm.	1
45 cm.	1
46 cm.	2
47 cm.	1
48 cm.	9
49 cm.	5
50 cm.	7
51 cm.	6
52 cm.	5
53 cm.	8
54 cm.	2
55 cm.	1
56 cm.	1
57 cm.	0
58 cm.	0
59 cm.	0
60 cm.	1
Total	54

It is seen from this table that in fifty-four trials, the 50% point found was never more than 10 cm. from the true value, 50 cm., and in 40 cases, or 74%, the value was within 3 cm. of the correct one.

A few experiments have also been made to compare more directly the results with the "Bruceton" method and with the conventional one. On five different days, a run of twenty shots was made on our standard cyclonite and the 50% point calculated by the Bruceton method. Immediately thereafter, forty shots were made alternately from a height five centimeters above and five centimeters below this fifty percent height. From these forty shots, a second fifty percent height was obtained. In order to give an idea of the variations experienced, the

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the results are given for the first twenty and second twenty shots of each batch of forty shots. These are shown in Table VI, where E means explosion and N means no explosion.

TABLE VI

A COMPARISON OF THE BRUCETON METHOD WITH THE
CONVENTIONAL METHOD

Expt. No.	Bruceton 50% Height	1st 20 Shots	2nd 20 Shots	40 Shots	Conventional 50% Height
1	50 cm.	55 cm. 8E 2N 45 cm. 5E 5N	7E 3N 5E 5N	15E 5N 10E 10N	45 cm
2	50 cm.	55 cm. 6E 4N 45 cm. 2E 3N	6E 4N 6E 4N	12E 8N 8E 12N	50 cm.
3	49 cm.	54 cm. 7E 3N 44 cm. 4E 6N	E 2N 1E 9N	13E 7N 5E 15N	50 cm.
4	48 cm.	55 cm. 9E 1N 45 cm. 2E 8N	8E 2N 1E 9N	17E 3N 3E 17N	50 cm.
5	53 cm.	58 cm. 6E 4N 48 cm. 3E 7N	6E 4N 5E 5N	12E 8N 8E 12N	53 cm.

The agreement between the two sets of results is very good, and both remain close to the true value of 50 cm.

The important feature of the Bruceton method is that it makes it extremely probable that the fifty percent height will lie within the reasonably narrow range in which shots have been made. The particular method adopted for finding the fifty percent height from the measurements is simply an objective way of smoothing the results and obtaining an answer. Actually, if one takes instead merely the midpoint of the range over which shots have been made, the results are very little affected. These statements are not meant to imply that the conventional method of making equal number of shots at several preselected heights will not give good results, but rather that the Bruceton method, we believe, will

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give a reliable answer with a smaller number of trials.

Design No. 2

This design lowers considerably the heights of fall for TNT, bringing it almost onto the scale of the 100 cm. machine, but alters the heights for the more sensitive compounds but slightly.

Tin foil, however, has very profound effects on the results, as was the case with design No. 1. Table III gives heights of fall for 50% explosions for designs Nos. 3 and 2, the latter with and without tin foil. Equally striking results are observed in Figure 3¹ which shows the sensitivities of mixtures of Cyclonite and TNT as function of composition and of the machine design. It is evident that almost any dependence of sensitivity on composition can be obtained at will and therefore we do not attribute any fundamental significance to the composition-sensitivity curves described by Urbanski*.

It is interesting to note that the effects here described for tin foil are apparently not connected with the chemical nature of this material. Very similar, although not necessarily identical results, have been also obtained on using cellophane or thin rubber membranes. Painting of the striker with rubber cement or depositing on it a thin layer of wax also result in extensive lowering of the 50% points and in "inversions" of the sensitivity order of some explosives. And yet, wax mixed with the same explosives acts as a phlegmatizer, i. e., raises the 50% points.

Design No. 4

This was used extensively during the summer of 1941 but is now not much used because of poor reproducibility of the results, in particular because of difficulties in preparing similarly acting metal components. It covers about the same range as No. 2. TNT does not fit onto the 100 cm. scale but all more sensitive compounds can be studied by this machine design. Table III gives comparative heights of fall for 50% explosions, but these have little absolute significance because of the wide scattering of data.

*Zeit. F. das ger. Schiess.-und Sprengsw. 33, 41 (1938)

¹ Figure 3 not available in original report.

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Design No. 5

Design No. 5 is the extreme case of inversions of the "conventional" order of sensitivities of common explosives, which is undoubtedly associated with the extreme confinement to which the materials are subjected here on impact. It is a very "sensitive" design, i. e., even insensitive explosives give low 50% points with it. Table III shows some of the results obtained, but absolute figures have little significance since the results are not very reproducible. This design is now in use only for very insensitive pure materials and for liquids, for which it is more suitable than the others. The chief objections are the difficulty of making reproducible indentations in the anvil, poor reproducibility of the results and the "unnatural" order of sensitivities of some of the common explosives, particularly of phlegmatized mixtures.

Design No. 6

Design No. 6 is still in a very experimental stage but appears to be suitable for work on insensitive compounds, provided it can be made sufficiently reproducible. It is more "sensitive" than the similar design No. 2, a finding that could have been expected because in other cases also the introduction of a central indentation in the anvil lowered the 50% points. In the present case, the lowering is particularly marked for insensitive materials, as is shown by Table III. This design is being considered for work with materials of the TNT type.

The preceding description seems to us to be ample evidence that it is futile to speak of the impact sensitivity of an explosive, even relative to that of a standard, unless the design of the machine used has been rigidly specified. It has been frequently stated in the literature that impact sensitivities of explosives form a very definite series but that frictional sensitivities form a different series, and that, depending on the amount of friction in a blow, different results may be obtained. This is undoubtedly true and, in fact, explains much of the data presented above. However, from the mechanical point of view, all machine designs described here deliver direct impacts, not frictional ones. We mean by a direct impact one in which the moving surface strikes a perpendicular blow on another one, while by a frictional impact is meant one in which a glancing blow is delivered. From this point of view all designs here given are substantially identical. They differ, however, very much in the extent to which the explosive itself is moved by the impact. In design No. 1, the explosive is freely scattered from under the striker; in designs

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Nos. 2 and 3 it is driven outwards against the resistance of the brass cap, which is always found bulged by a ring of the explosive substance after a negative trial; in designs Nos. 4 and 6 the material is partially driven towards the center of the anvil, where it is subjected to high compression. Finally, in designs using tin foil or other soft materials, particularly in design No. 5, the motion of the explosive is greatly hindered by the increased friction against the soft, yielding material. These statements are all confirmed by actual observations on the explosives after negative trials and they must account for the wide variety of the results obtained.

In service use an explosive may be subjected to a great variety of sudden stresses and no single laboratory test can be expected to reproduce them all at once. Worse than that, it is very difficult to decide which laboratory design correctly reproduces a given service hazard. A large body of empirical knowledge has been accumulated, however, which would suggest that designs numbered before as Nos. 1, 2, 3, and 6(without tin foil) measure reasonably faithfully the relative hazards encountered in handling several explosives considered. These designs, therefore, we now prefer to use, although we believe that in order to explore more thoroughly the dangers of a given new material, it should be tested on more than one design in the laboratory and then subjected to very extensive large scale trials.

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REPORT II

Bruceton, Pennsylvania
July 4, 1944

Report to: Dr. E. H. Eyster
From: Rogers F. Davis
Subject: A Report on the Behavior of Explosives to
Mechanical Shock

From some of the literature (1, 2.....22) and past research there has developed the idea that to investigate explosives as to their response to mechanical shock will arrange these materials in a general order of behavior or so-called sensitivity. This general order is thought to be of value in regard to practical handling of various explosives in that individuals may learn of dangerous, shock-sensitive materials and may thereby minimize accidents by observing carefulness. Too, this general order is thought to reveal commercial and military possibilities of a given explosive as far as general handling is concerned.

Investigating the behavior of explosives to impact or shock usually involves placing a small quantity of material on a firm base or anvil and inserting through a guide ring a piston or striker which is brought to rest atop the small charge of explosive. A weight or hammer of known mass is then permitted to fall under gravitational influence so as to cause impact on the striker-explosive combination. The necessary height fall or drop-height to cause explosion becomes the characteristic evaluation of the sensitivity of the explosive. Most investigators use as the criterion the minimum drop-height needed to produce an explosion in at least 10 trials. Many evaluations have been reported in past literature (1, 2.....20) without the proper emphasis on a description of the method of testing the explosive and on the degree or intensity of explosions resulting from the listed drop-heights or impact energies. The method of testing is most important, as slight variation in the construction of strikers and anvils will change the orders of sensitivity of explosives. Strong evidence of these phenomena is seen from various designs described in this report.

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Other methods of evaluating sensitivity involve measuring the amount of gas produced during a given explosion. The Rotter machine is perhaps the most familiar in this realm. Such procedure is definitely more scientific than previous evaluating methods, but has the disadvantage of being time consuming.

Some investigators (Dr. W. S. Koski, Hercules Powder Company) have attempted to measure the intensity of sound of explosion as a criterion for the amount of material exploding; however, interfering noises make this approach difficult.

At Bruceton explosions are detected by auditory means, and it has become the practice to identify and compare explosives by the drop-height needed to produce explosions in 50% of the trials. Also kept in mind are the minimum drop-height to produce an explosion and the drop-height at which explosions occur in every trial.

The 50% explosion drop-height was chosen as an abbreviated 20-trial determination or "run" was developed (21) in 1941 for which the 50% explosion height was accurate. The procedure involved is discussed later in this report under the section describing the No. 3 Bruceton design. The conventional procedure is to carry out a series (20 or more) of trials at various drop-heights to obtain 0-100% explosibility; which involves at least 100-200 trials per explosive or sample. Because of the large number of samples at Bruceton and the limited supply of impact machines, it was essential that an abbreviated procedure be developed for routine determinations. The conventional procedure has likewise been employed at Bruceton whenever extensive studies were pursued.

O. S. R. D. Report No. 804 (21) discussed sensitivity studies with some six Bruceton designs used at that time. By a design is meant a given set of conditions in the form of the type of striker and anvil used. Since August, 1942, there have been developed methods designated as Designs No. 7 - 13. All of these latter designs are used with a large impact machine which has a maximum drop-height of 337 cm. or about 11 feet with either a 2.5 or 5.0 kilogram weight. Designs No. 1-6 were all used with smaller machines of 100 cm. maximum drop-height. The present writing is to discuss the more important results obtained with designs 7 - 13 and additional (since 1942) data from designs 1, 3 and 5.

The interpretation of sensitivity data obtained by the conventional method of testing has produced some interesting and confusing aspects.

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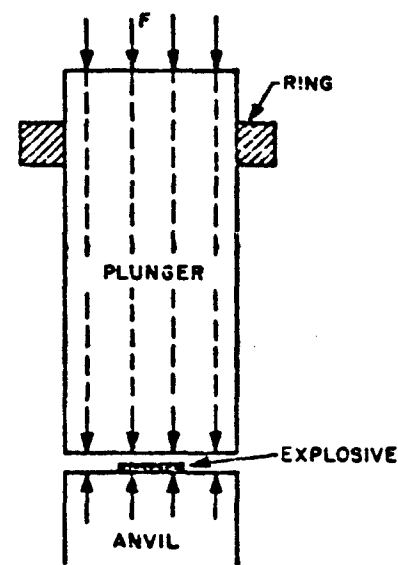
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We obviously know that the percent explosibility or the probability to explode is a function of the drop-height, but doubt has existed as to the exact nature of this function. When probability to explode (synonymous with % explosions or % explosibility) is plotted as a function of the logarithm of the drop-height, an elongated S-shaped curve results. This becomes more prominent when a large (at least 100) number of trials are carried out for a given drop-height. Taylor and Weale (9/16) attempted to treat the curve as a statistical distribution obeying the Maxwell-Boltzman distribution law. This was likewise thought by this author in that these curves are similar to the integrated form of the Gaussian normal error function and that probability is involved in sensitivity studies. However, it seems that the curves are similar only in shape.

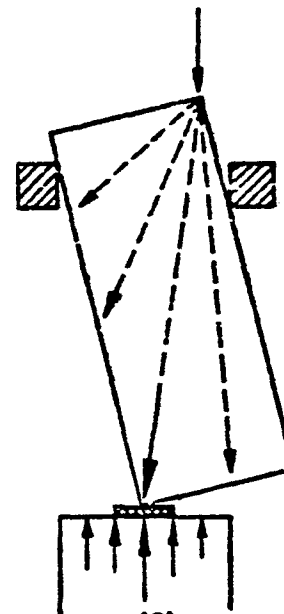
The relationship may be a linear one, with a general type equation of the form $S^K = EA$, where S is the drop-height, E the % explosibility or probability to explode, K is the slope and A the theoretical E -intercept (when $S=0$) on a log-log plot. A has a large negative value and possesses no physical significance. It is needed only to give a specific equation for each explosive; thus with knowledge of A and the slope, K , the theoretical sensitivity curve can be drawn.

Although the theoretical relationship between E and S may be linear, the practical relationship becomes the complex S-shaped curve. An equation to fit these curves is meaningless, as many trials are needed to obtain the exact shape of the tails of the curve. The tails are most likely caused by the fact that the drop-hammer does not fall in the same manner for each trial. Identical hits or impacts on the striker are likewise not obtained for each trial; and as a result, certain stress concentrations from irregular impacts produce certain or doubtful explosions (depending upon the explosive) at drop-heights which theoretically should produce no explosions, or likewise produce a failure to explode at drop-heights which theoretically should produce explosions in every trial. Even the slightest clearance, .001 - .002", between the guide ring and the striker leaves a region for mobility of the striker and produces irregular impacts. Unfortunately, such clearance is needed with a striker-guide ring design, to permit removal and insertion of the striker. Even a slight irregularity during an impact process of this kind can cause enormous energy dissipation or concentration. Diagrams 1-4 give a few of the possibilities during impact of this type which would cause deviations. Another factor, discussed later, is that the elastic properties of a given explosive vary, which in turn causes deviations in the pressures produced during such impact processes.

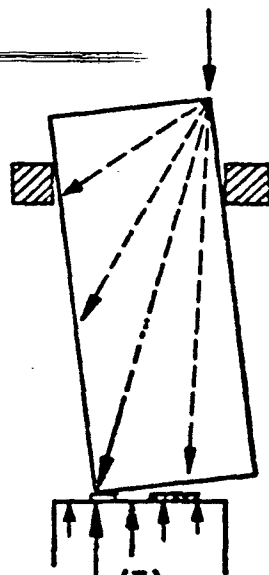
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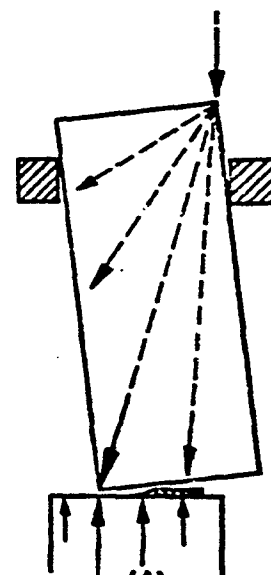
(1)
IDEAL CONDITIONS



(2)
EXPLOSION AT UNEXPECTED
DROP-HEIGHT



(3)
DOUBTFUL EXPLOSION AT
UNEXPECTED DROP-HEIGHT



(4)
FAILURE AT UNEXPECTED
DROP-HEIGHT

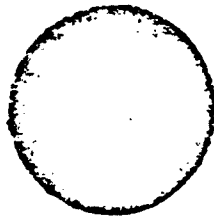
A FEW OF THE POSSIBLE DEVIATIONS DURING AN IMPACT
PROCESS SUCH AS IS PRESENT IN SENSITIVITY STUDIES.

II-6

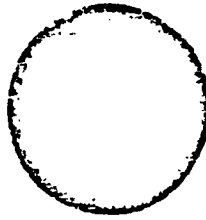
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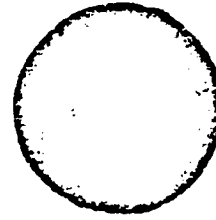
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(1)



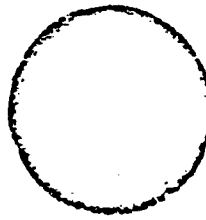
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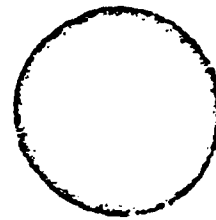
(3)



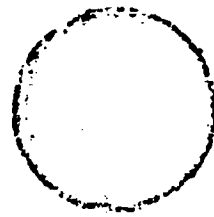
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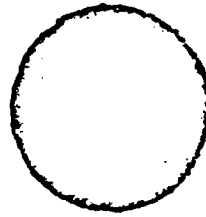
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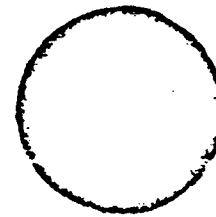
(6)



(7)



(8)



(9)

SHOWN ABOVE ARE 9 SUCCESSIVE CARBON PAPER IMPRINTS OF THE IMPACT OF A 50 CM. FALL OF A 2.5 KILOGRAM HAMMER ON A 1 1/4" DIAMETER STRIKER. THESE IMPRINTS SHOW THE BEHAVIOR OF THE HAMMER DURING IMPACT. ALSO SHOWN ARE SUCCESSIVE IMPRINTS OF THE STRIKER-ANVIL SURFACES FROM THE IMPACT OF A 2.5 KILOGRAM HAMMER FALLING 50 CM. THESE SERVE TO ILLUSTRATE SLIGHT VARIATIONS AS THE COLOR INTENSITY IS SEEN TO VARY AMONG IMPRINTS

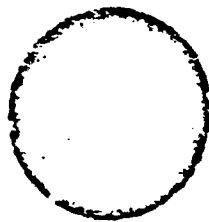
DROP-HAMMER ON STRIKER

II-7

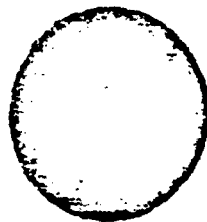
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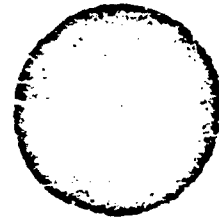
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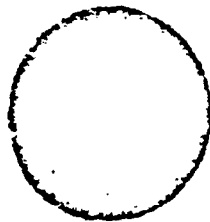
(1)



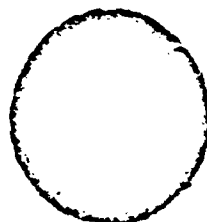
(2)



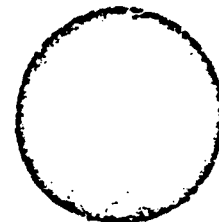
(3)



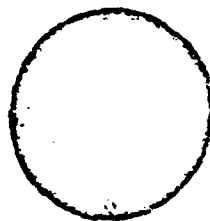
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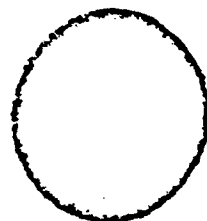
(5)



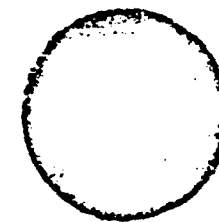
(6)



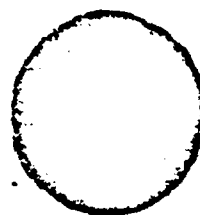
(7)



(8)



(9)



(10)

STRIKER-ANVIL SURFACES

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Another approach to the interpretation of sensitivity results is to plot the % explosions as a function of the logarithm of the drop-height on probability graph paper. The tails of the S curve are here avoided and a linear curve results. The use of probability paper is based upon the assumption that theoretically the S curves are asymptotic at the lower and upper ends, i. e., there is always the probability of an explosion as zero drop-height is approached and likewise there is always the probability of a non-explosion as infinite drop-height is approached.

In certain portions of this writing sensitivity curves will be shown. These will be identified as the practical or actual S-shaped curves obtained by plotting the % explosions or probability to explode (P_e) as a function of the drop-height on semi-logarithmic graph paper; as a general theoretical linear curve on a log-log plot of the same, although the opinion of late is that the log-log plot is only an approximation. In reality this plot removes only the lower tail of the S-curve and produces strange orders of sensitivity at the X-axis intercept; however, these graphs are presented to illustrate this point of discussion.

Practical curves will be identified by the graphical value of the 50% explosion drop-height and the slope of the curve at that particular point. "Theoretical" curves will in most cases be identified by a general equation of the form: $\log E = K \log S - \log A$, where E is the % explosions, S the drop-height, K the slope and A the negative E intercept when $S=0$. Log A and K will be calculated from known rounded values of E and S.

In addition to these two types of plots, there will appear plots on probability graph paper. These curves will be identified by the 50% explosion drop-height and the slope of the curve. A large value of the slope indicates that the explosive in question requires a wide range of drop-height to produce <1 to >99% explosibility; while a small slope likewise indicates that the explosive is influenced greatly by a reasonably small range of height.

It will be observed that with these latter probability plots, different orders of sensitivity may occur at the <1% end of the curve, i. e., the y-intercept. It must be remembered that such values are extrapolations and undoubtedly are beyond the accuracy of the impact machine.

Slopes of the elongated S-curves will be determined by drawing a tangent at the 50% explosion point of the curve and measuring with a

H-9

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protractor the angle formed with the X-axis. The tangent (from tables) of this angle becomes the slope of the curve at the 50% explosion point.

For the probability curves, the slopes will be determined by the familiar formula $y_2 - y_1$, where X_2 is .90

$$\frac{X_2 - X_1}{X_2 - X_1}$$

(90%) and X_1 is .10 (10%) in most cases. Where a curve does not reach 90% explosions, appropriate %'s are chosen.

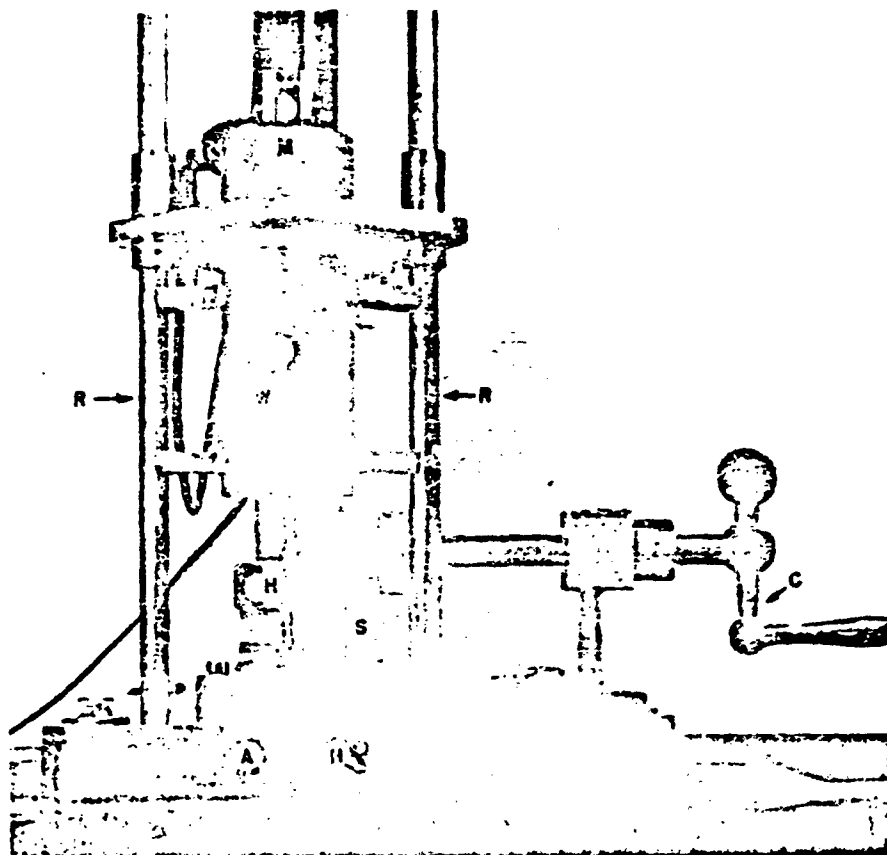
The Bruceton No. 3 Design

Since O. S. R. D Report No. 804 (21) the No. 3 or brass cup design has been adopted as one of the standard sensitivity tests at Bruceton. The design is illustrated in Plate I. The anvil or base (A) consists of a hardened ketos steel cylinder of 1 1/4" diameter and 2" height. The plunger or striker (S) is 1/2" diameter ketos drill rod which is machined to a taper at one end to fit a brass cup of 0.308" i.d. The tapered end is ground to 0.306" diameter for the standard test. Plate II shows another view of the anvil (A-3), striker (S-3) and brass cups (C-3). Plate III presents a side view of the striker-anvil holder device (H-II). The same design is applicable to the large impact machine and the respective parts are seen in Plates II and III. Plate III shows this holder with a design No. 1 striker inserted.

The No. 3 design is ideal for the initiating and booster type of explosive, but is limited for materials of the TNT class. The maximum drop-height is restricted to 100 cm., as the striker tips tend to bulge so as not to fit the cup. These tips likewise will develop cracked edges, which lead to erratic results due to localized pinching and confinement. Booster-type of explosives (RDX, Tetryl) are most affected by cracked strikers, while initiators such as PETN, lead azide and lead styphnate are unaffected.

For routine sensitivity determinations the so-called "Bruceton Method" is used in reporting results. The principle was developed in 1941 by Drs. G. H. Messerly and D. P. MacDougall (21). A series of 20 trials is carried out as follows: Assume that a trial registered E, or explosion, at 50 cm.; the procedure is to lower the drop-height in 5 cm. increments until a failure to explode, or N, is obtained, then the height is increased by 5 cm. until an explosion results, and so on.

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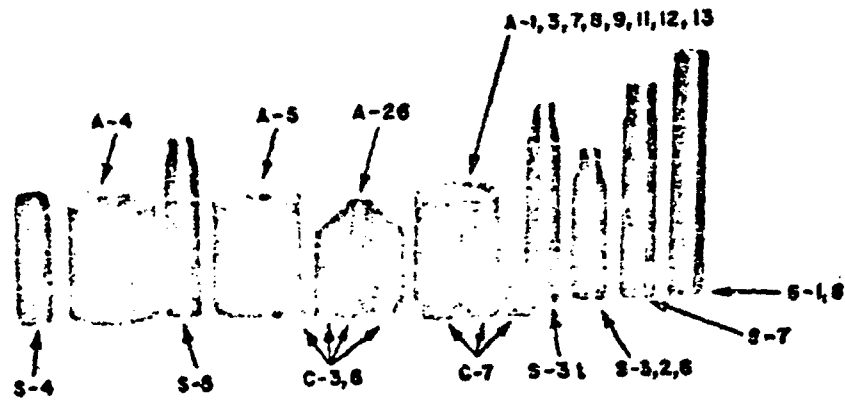


W - 5.0 KILOGRAM DROP-HAMMER
R - GUIDE RODS TO CONTROL PATH OF FALLING HAMMER
C - CRANK TO RAISE AND LOWER HAMMER
H - ANVIL-STRIKER HOLDER
M - ELECTROMAGNETIC DEVICE TO HOLD HAMMER
S - STRIKER INSERTED IN BRASS CUP
A - ANVIL OR BASE

PLATE I
THE BRUCETON DESIGN NO. 3

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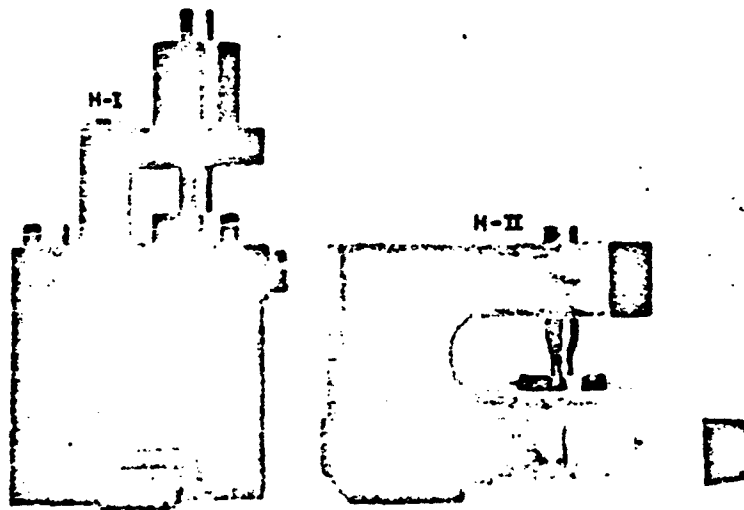


S-1,6	▪	STRIKER FOR DESIGNS NO. 1, 6
S-3,2,6	▪	▪ 3,2,6
S-31	▪	DESIGN NO. 3, LARGE IMPACT MACHINE
S-4	▪	▪ 4
S-5	▪	▪ 5
S-7	▪	▪ 7
A-1,3,7,8,9,11,12,13	▪	ANVIL FOR DESIGNS NO.1,3,7,8,9,11,12,13
A-2,6	▪	ANVIL FOR DESIGNS NO. 2,6
A-4	▪	▪ 4
A-5	▪	▪ 5
C-3,6	▪	BRASS CUPS FOR DESIGN NO.3
C-7	▪	COPPER CUPS FOR DESIGN NO.7

PLATE II
STRIKERS AND ANVILS FOR VARIOUS DESIGNS

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**H-I = HOLDER FOR DESIGNS NO. 1, 7, 8 AND USED WITH LARGE
IMPACT MACHINE. DESIGN NO. 1 IS SHOWN.**

**H-II = HOLDER FOR SMALL IMPACT MACHINE DESIGNS NO. 1-6.
SIDE VIEW OF NO. 3 IS ILLUSTRATED.**

PLATE III
ANVIL-STRIKER HOLDERS

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Thus,	<u>Trial</u>	<u>Height</u>	<u>Result</u>
	1	50	E
	2	45	E
	3	40	N
	4	45	E
	5	40	N
	6	45	N
	7	50	E etc.

The 50% mark, or height at which explosions occur in 50% of the trials, is used to identify explosives in routine determinations. This value is calculated as follows: Taking an actual determination or "run" for RDX:

<u>Trial</u>	<u>Height</u>	<u>Result</u>	<u>Trial</u>	<u>Height</u>	<u>Result</u>
1	50	E	11	50	E
2	45	N	12	45	N
3	50	E	13	50	N
4	45	E	14	55	E
5	40	N	15	50	N
6	45	E	16	55	N
7	40	N	17	60	E
8	45	E	18	55	N
9	40	N	19	60	E
10	45	N	20	55	E

Condensing actual trials:

<u>Height</u>	<u>ΣE</u>	<u>ΣN</u>	<u>%E</u>
60	2	0	100
55	2	2	50
50	3	2	60
45	3	3	50
40	0	3	0

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If a trial registered E at 50 cm., it is assumed that under the same conditions for that particular trial there would also have been explosions at any drop-height above 50 cm. Likewise if a trial at 50 cm. registered failure, it is assumed that failures would have occurred at any height below 50 cm. Applying these principles to actual trials we obtain,

<u>Height</u>	<u>ΣE</u>	<u>ΣN</u>	<u>%E</u>
60	10	0	100
55	8	2	80
50	6	4	60
45	3	7	30
40	0	10	0

By inspection we observe that the 50% explosion height is between 45 and 50 cm. To calculate the value in cm., to be subtracted from 50 cm. or added to 45 cm., proportion is applied.

$$\frac{\text{the height in cm. to be added to 45 cm.}}{\text{the increment of height between 45 and 50 cm.}} = \frac{50 - \%E \text{ at 45 cm.}}{\%E \text{ at 50 cm.} - \%E \text{ at 45 cm.}}$$

numerically equivalent to:

$$\frac{X}{5} = \frac{20}{30}, \quad X = 3.3 \text{ and } 50\% \text{ explosion height is } 45 + 3.3 \text{ or } 48.3 \text{ cm.}$$

also,

$$\frac{\text{the height in cm. to be subtracted from 50 cm.} - \%E \text{ at 50 cm.} - 50}{\text{the increment of height between 45 and 50 cm.}} = \frac{\%E \text{ at 50 cm.} - \%E \text{ at 45 cm.}}{\%E \text{ at 50 cm.} - \%E \text{ at 45 cm.}}$$

numerically equivalent to:

$$\frac{X}{5} = \frac{10}{30}, \quad X = 1.7 \text{ and } 50\% \text{ explosion height is } 50 - 1.7 \text{ or } 48.3 \text{ cm.}$$

With sensitive materials of 50% explosion heights in the order of 6-15 cm., the increment of height is 2 cm. instead of 5 cm. The increment amounts in a general way to 10% of the height.

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A standard is a common explosive such as RDX, PETN, or Tetryl which is tested daily to indicate the condition of the design for that particular date. RDX is the most common standard substance employed for Design No. 3.

The 50% explosion height represents the most accurate portion of the curve obtained when probability to explode is plotted as a function of drop-height in the case of a large number of trials at given drop-heights from 0 to 1.0 (100% E) probability of E. The Bruceton Method is accurate within $\pm 5-10\%$ for the 0.5 probability height and serves as a rapid means of evaluating explosives in a comparative sense. It must be remembered, however, that this time saving method is accurate for the 50% explosion drop-height only.

The No. 3 design was likewise employed to investigate a number of common and newer explosives in the conventional procedure. These data are summarized in Table I and treated graphically in Figures 1-6. Significant data are listed on the graphs.

From experience it has been found that certain factors affect results obtained with Design No. 3. Such variables as the diameter of the striker tips, cracks developing along striker tip edges, the nature of the anvil surface, the nature of the container and the amount of explosive placed in the cups all affect results.

Conditions of the striker and anvil were varied in an investigation involving PETN and RDX. It was observed that strikers with cracked edges which also possessed a diameter of <0.306 " affected RDX more than PETN. A relatively sensitive substance such as PETN seems so classed regardless of conditions, it would seem. Changing the diameter of the striker tip from normal 0.306 " to $0.304-0.300$ " deviated the RDX 50% explosion height from normal 48 cm. to 35 cm., while strikers with cracked tip edges and undersized diameters gave values in the order of 30-35 cm. PETN was lowered, if any, about 2-4 cm. below normal 30 cm. Table II shows a summary of these results.

The weight of explosive tested was varied with the explosives RDX, PETN and Tetryl. Individually weighed charges were used for 20 trials at each drop-height to obtain data presented in Table III. Abbreviated "runs" by Bruceton Method (ibid.) with PETN gave for 5, 10 and 20 mg. charges 50% explosion drop-heights of 19.2, 17.5 and 21.0 cm. respectively. Normal values here with 30-35 mg. charges average about 30 cm.

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TABLE I
DATA BY CONVENTIONAL METHOD FOR DESIGN NO. 3

Drop- Height (Cm.)	Nitromonite		Lead Styphnate		Mercury Fulminate		PETN		RDX		NENO		Telryl		EDNA		Explosive D		Sisinate	
	Trail	SE	Trail	SE	T	SE	T	SE	T	SE	T	SE	T	SE	T	SE	T	SE	T	SE
4	40	2.5			20	0														
6	40	22.5			20	0														
8	40	65	20	0	20	10														
10	40	95	20	10	20	15														
12	20	92.5	20	85	20	50														
14	20	95	20	95	20	100														
15							20	0							20	0				
16	20	95	20	100																
18	20	90																		
20	40	92.5					20	35	20	5			20	0	20	0				
22																				
25	20	100					20	40												
30							40	50	40	22.5	20	50	40	2.5	40	5				
35							20	65												
40							20	75	20	55	20	55	20	0	20	47.5				
45							20	75	20	45			20	55	20	25				
50							20	80	20	50	20	70	20	15	20	40				
55																				
60							20	92.5	40	7.5	20	70	40	62.5	40	30	20	10		
70									20	85	20	65	20	40	20	50	20	20		
75							20	100	40	17.5			20	100	20	50				
80											20	85	20	100	40	47.5	20	40	20	40
85															40	70			20	40
90															40	67.5	20	95	20	35
95															20	80	20	95	20	55

	Picric Acid		Favonite		TND		Regular TNT		KClO ₃		Emuret		Micro-Milled TNT		Lead Styphnate*		Mercury Fulminate*		PETN*	
	Trail	SE	Trail	SE	T	SE	T	SE	T	SE	T	SE	T	SE	T	SE	T	SE	T	SE
4																				
6																				
8																				
10																	20	10		
12																	20	5		
15															20	0				
16															20	20	20	5		
18															20	25				
20															20	75	20	50		
22															20	95				
25															20	100	20	25	40	0
30																	20	100	40	2.5
35																			40	7.5
40																			40	15
45																			40	22.5
50																			40	25
55																			40	27.5
60																			40	42.5
70			20	0															40	50
80																				
85	20	20	20	5	20	20	20	10	20	15	20	0	20	0					40	55
90	20	30	20	25	20	15	20	10	20	5	20	5	20	0					40	52.5
95	20	30	22	35	20	35	20	5	20	25	20	10	20	0						

*/ Kg. Drop-Hammer (all other data for 5 Kg. Hammer)

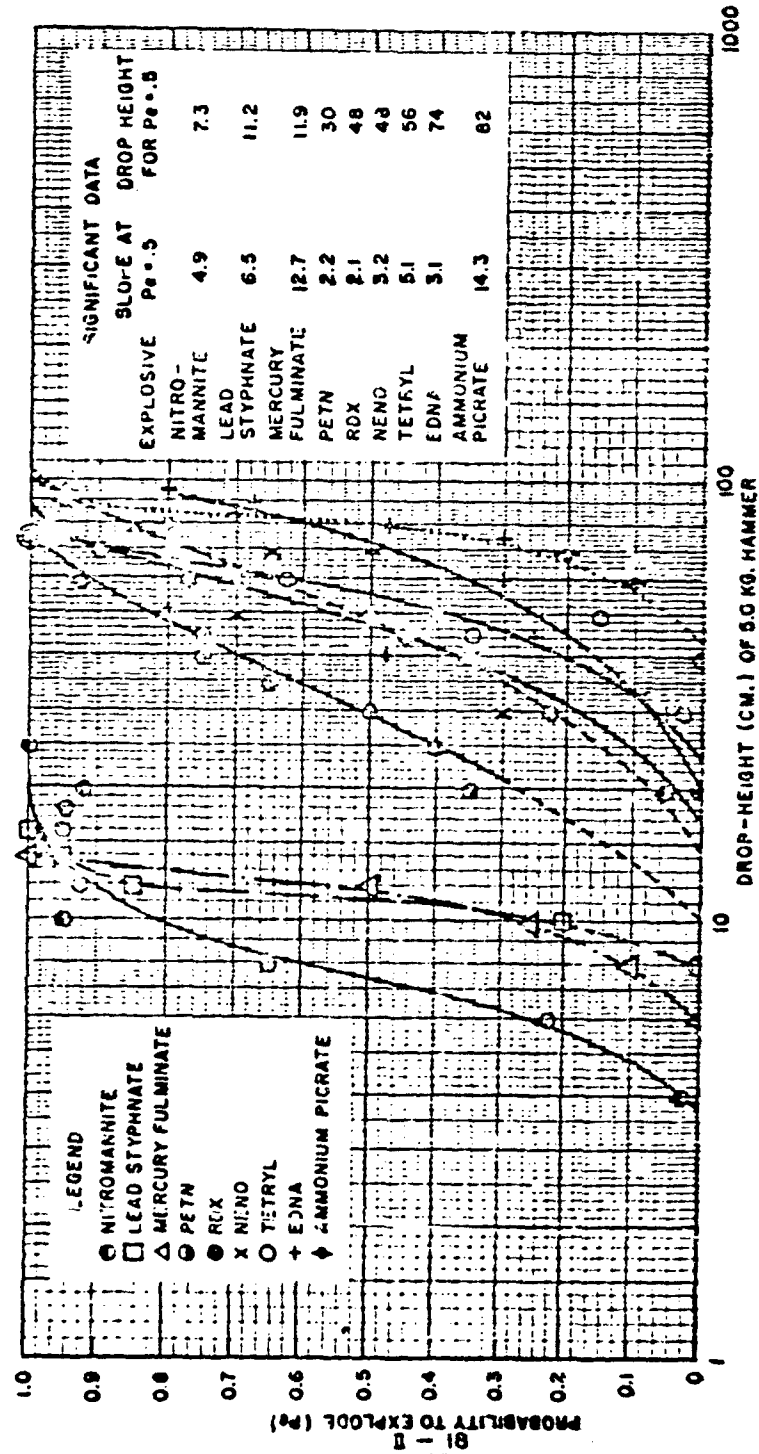


FIG.1 PRACTICAL SENSITIVITIES BY DESIGN NO. 3

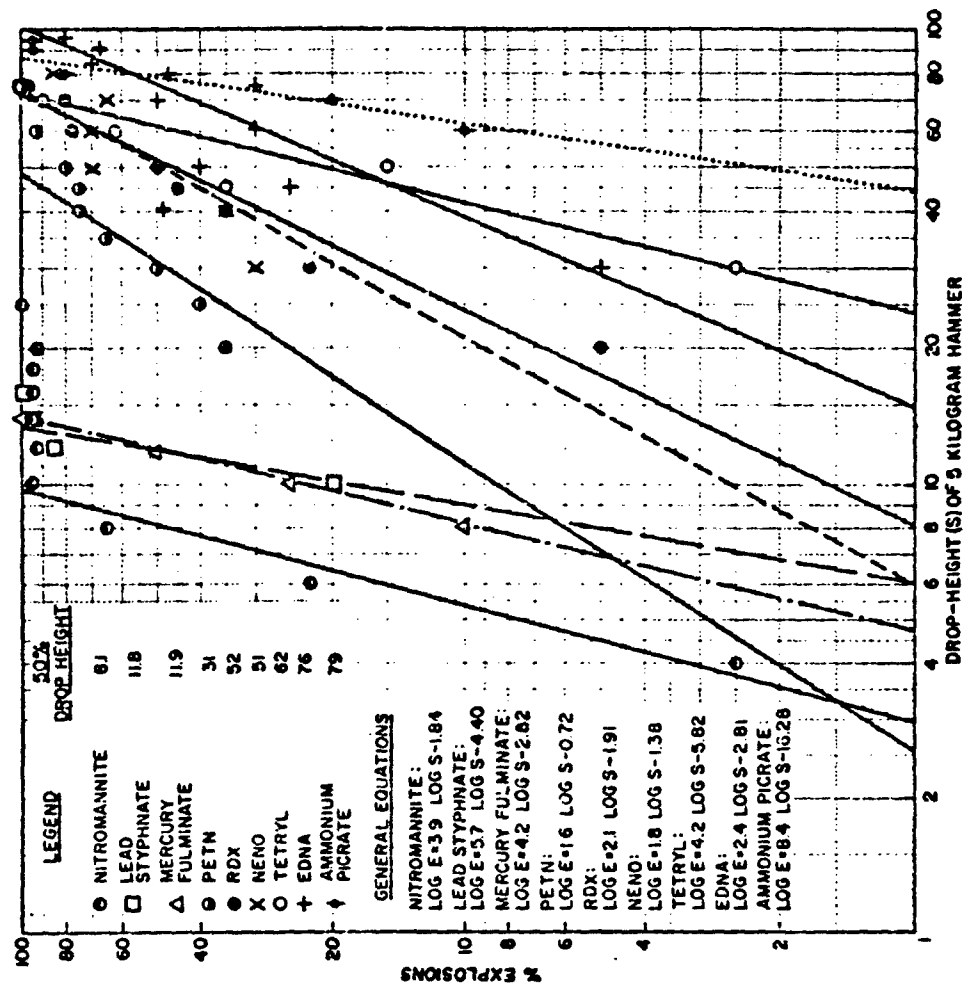


FIG. 2 THEORETICAL SENSITIVITIES BY DESIGN NO. 3

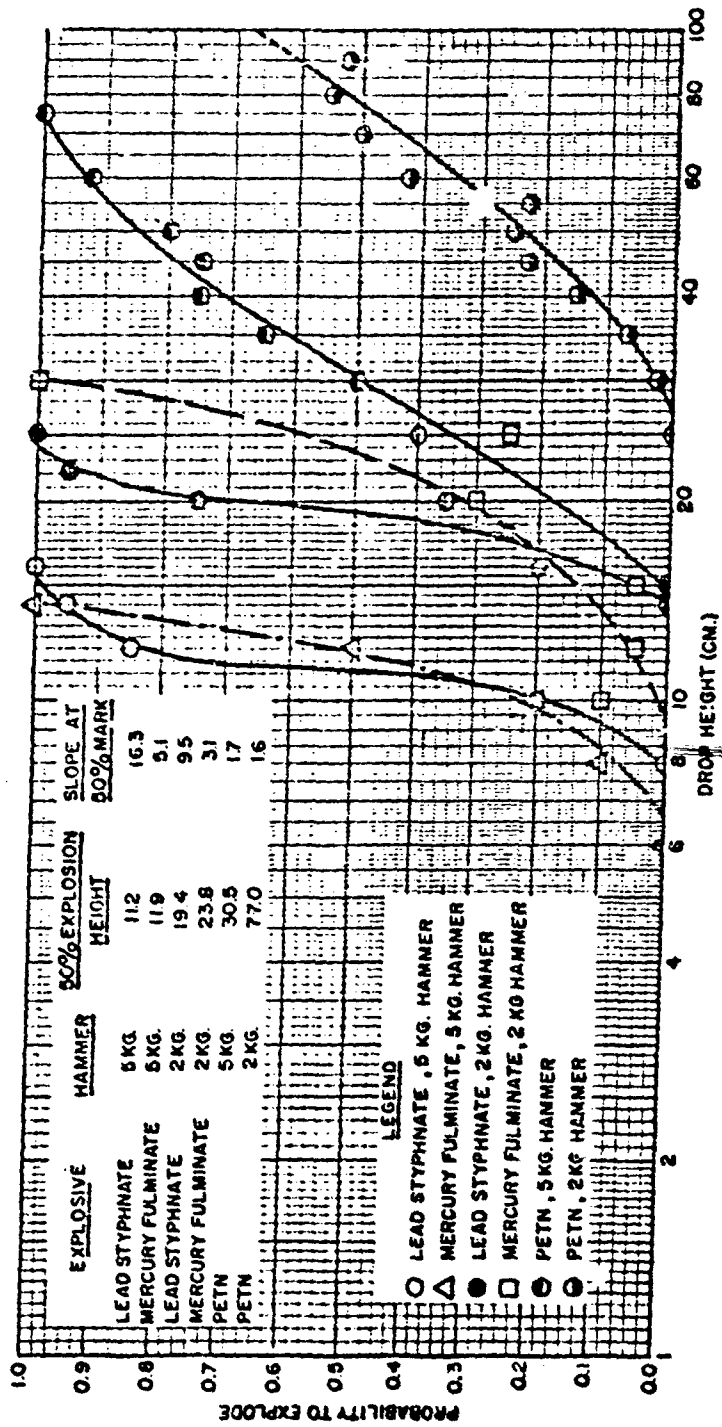


FIG. 3 COMPARATIVE SENSITIVITIES BY DESIGN NO.3

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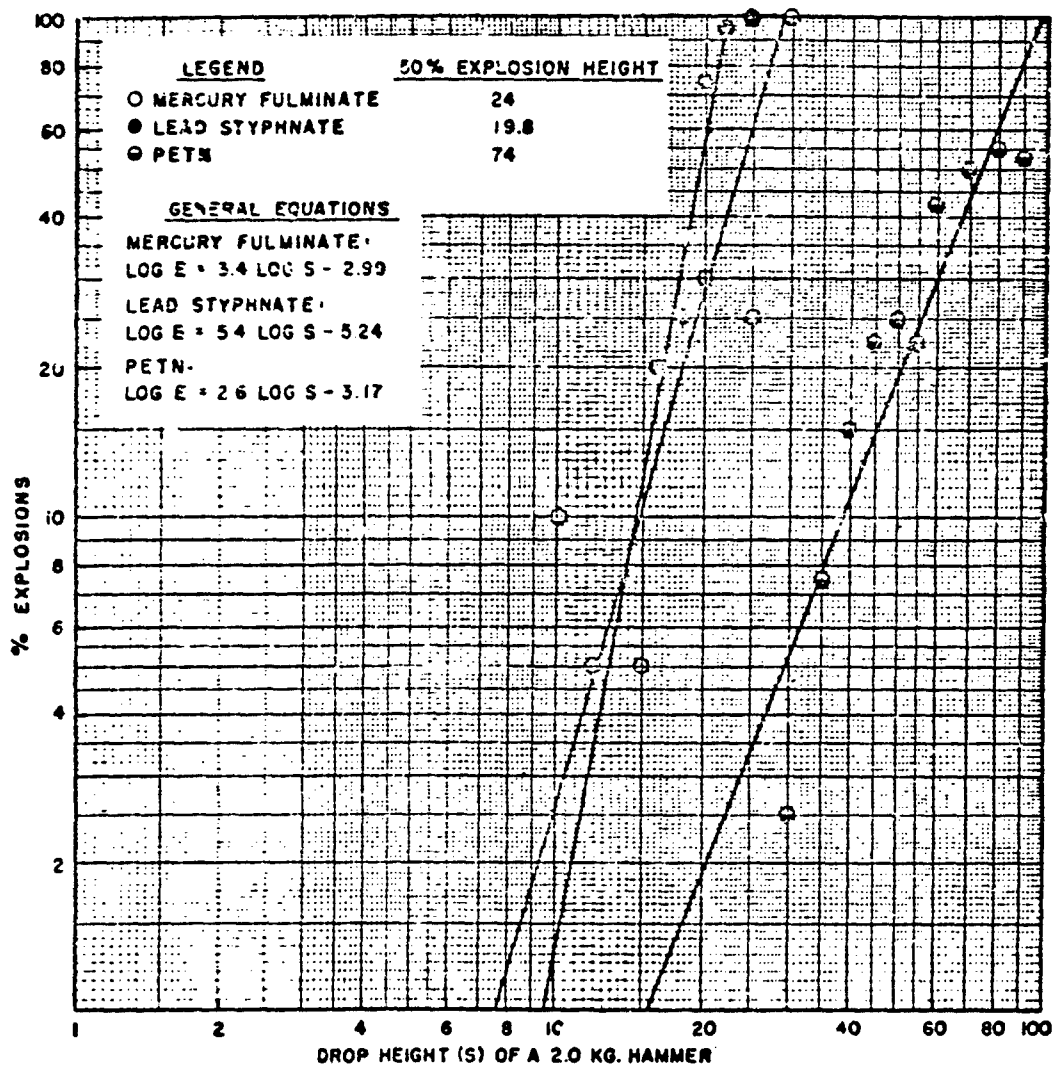


FIG. 4 THEORETICAL SENSITIVITIES BY DESIGN NO. 3

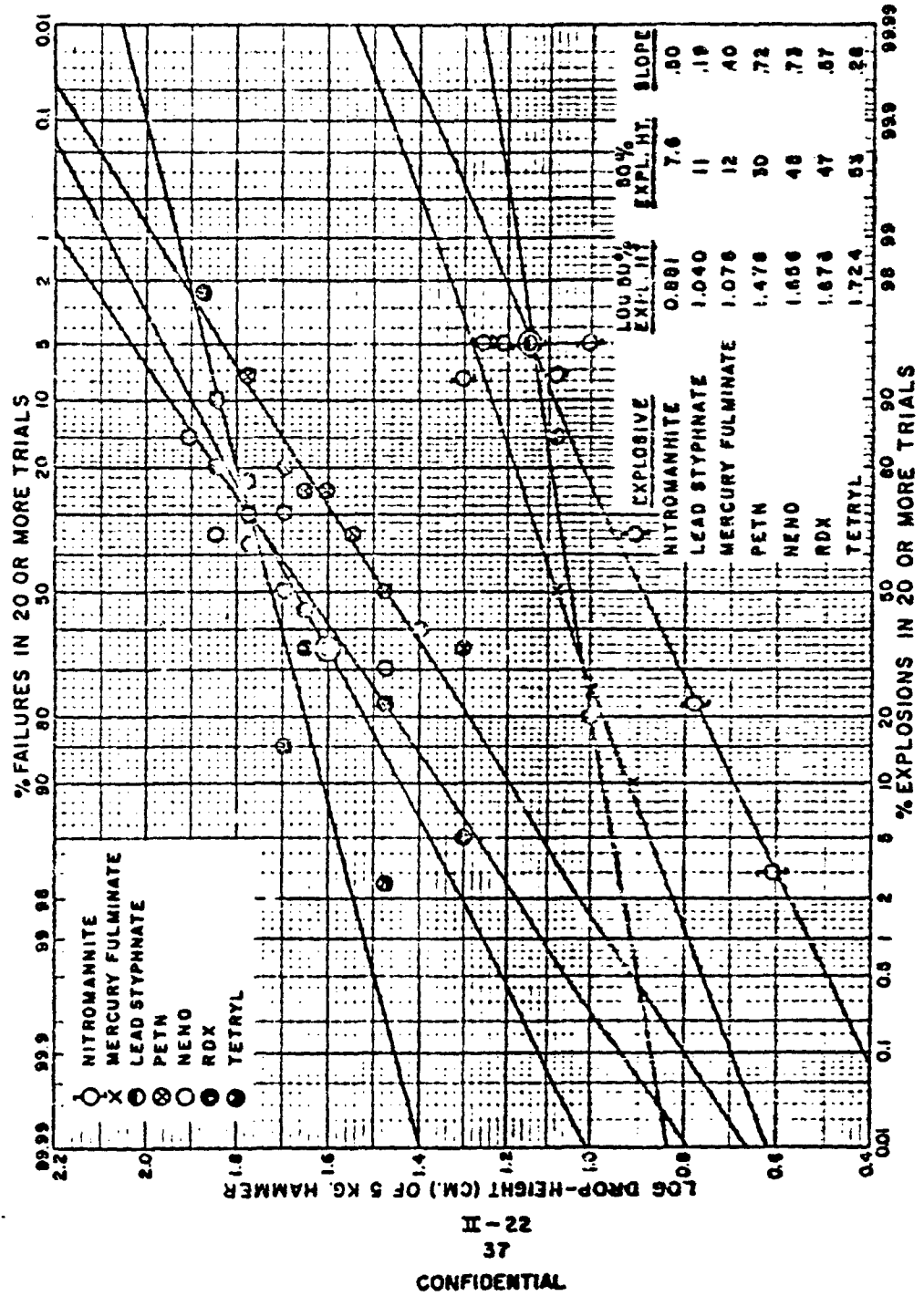


FIG. 5 SENSITIVITIES BY DESIGN NO. 3

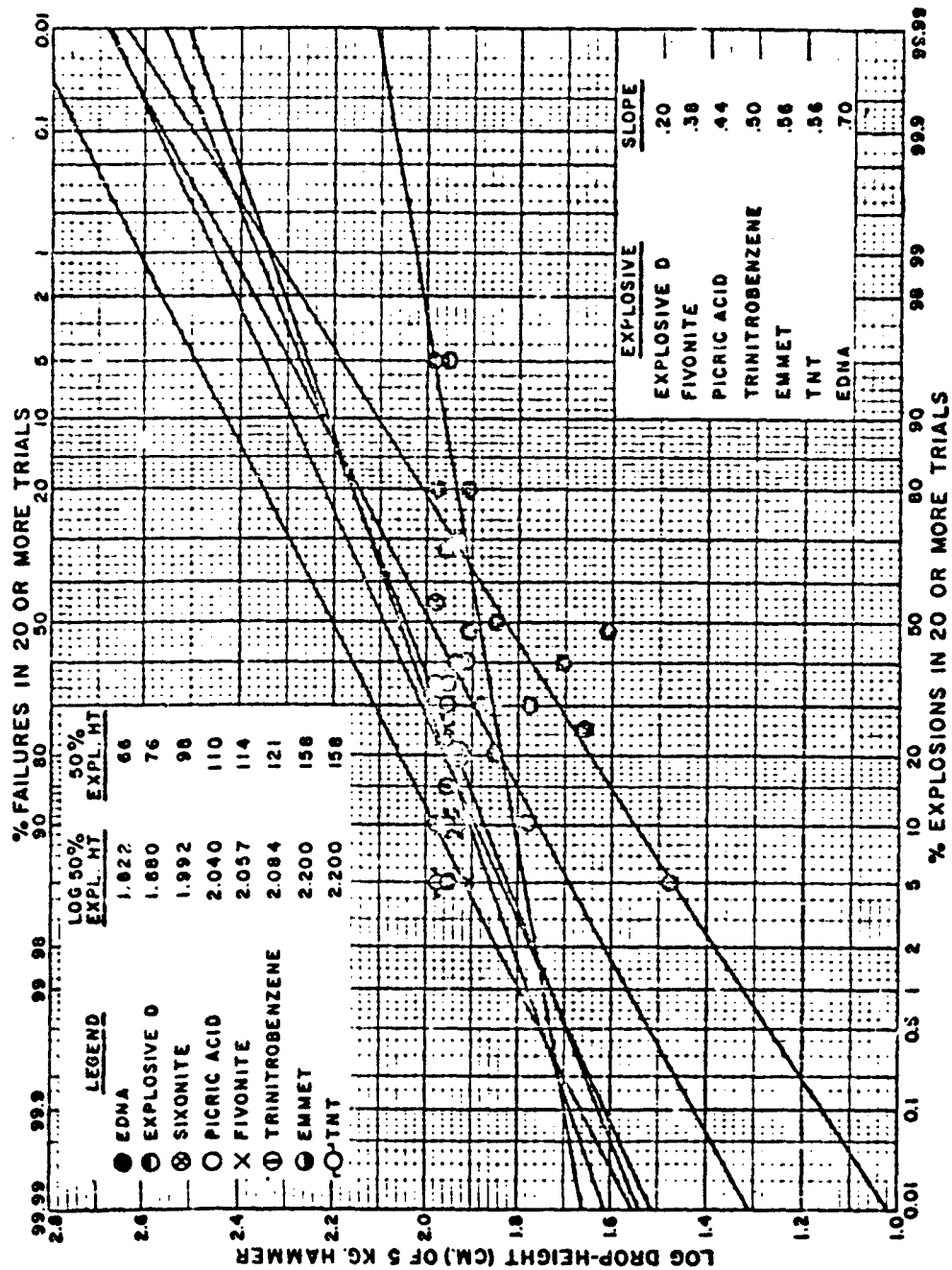


FIG. 6 SENSITIVITIES BY DESIGN NO. 3

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Figures 7-9 show graphic treatment of data from Table III. As the amount of material tested decreases for PETN, the material requires less energy for detonation; but as the charge weight exceeded 30 mg., a relatively constant drop-height was needed to give an explosion probability of 0.5. With RDX, the 50% marks increased with the charge weight; however, as the drop-height exceeded 70 cm., the probability of explosion appeared constant and the curves merge at 75 cm. The same behavior held with Tetryl, with merging at 90 cm. drop-height.

TABLE II

**SUMMARY OF 50% EXPLOSION HEIGHTS FOR PETN AND RDX UNDER
VARIED CONDITIONS WITH BRUCETON NO. 3 DESIGN**

<u>Substance: PETN</u> <u>- Condition -</u>	<u>Striker Diameter</u>			
	<u>0.306"</u>	<u>0.304"</u>	<u>0.302"</u>	<u>0.300"</u>
Striker Edges normal (slightly sanded) normal procedure	37.7	31.2	31.0	35.5
	27.5	27.1	34.2	---
	25.0	30.0	34.2	38.9
Striker edges sharp, no sanding	27.9	22.5	28.3	31.3
	27.5	32.0	37.7	33.2
	27.5	23.7	28.0	29.0
Striker edges normal, anvil rough	28.7	30.0	30.0	31.9
Striker edges sharp, anvil rough	32.9	29.0	29.0	30.0
Striker edges cracked, normal anvil	21.9	33.5	27.5	28.1
Striker edges cracked, rough anvil	21.9	27.5	27.1	37.5
Striker edges normal, 2 scoops PETN (60 mg)	39.1	27.5	36.0	40.0
	31.1	30.6	31.8	37.4

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TABLE II (cont'd)

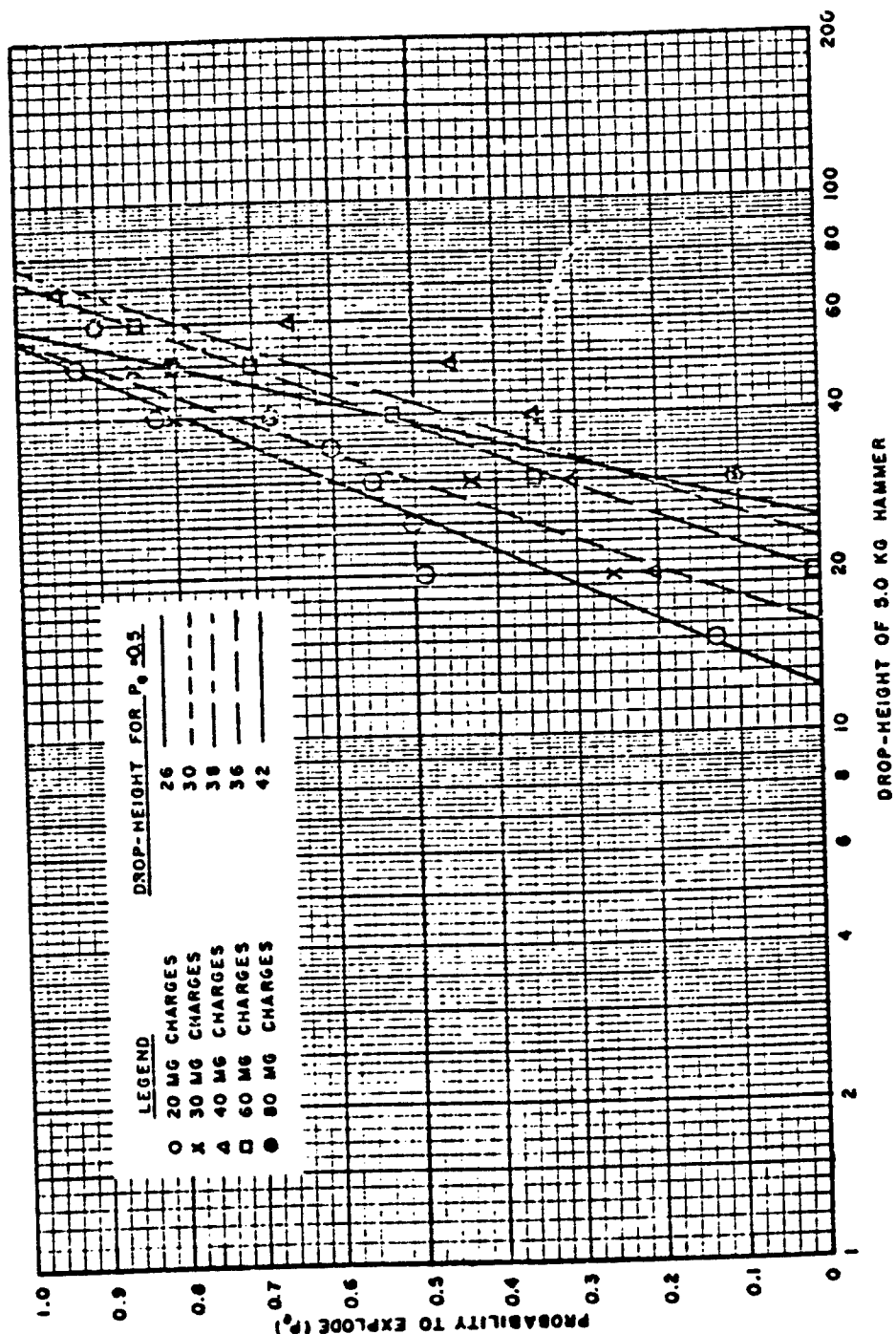
**SUMMARY OF 50% EXPLOSION HEIGHTS FOR PETN AND RDX UNDER
VARIED CONDITIONS WITH BRUCETON NO. 3 DESIGN**

<u>Substance: PETN</u> - Condition -	<u>Striker Diameter</u>			
	<u>0.306"</u>	<u>0.304"</u>	<u>0.302"</u>	<u>0.300"</u>
Striker edges sharp, 2 scoops PETN	32.1	30.6	45.0	32.3
	36.2	29.2	36.2	38.8
Striker edges normal, 2 scoops, rough anvil	34.2	30.6	----	----
Striker edges sharp and cracked, 2 scoops, and rough anvil	37.5	31.4	34.2	35.0
	34.2	28.1	30.6	34.0
 <u>Substance: RDX</u>				
Normal Procedure	47.4	33.3	40.8	34.0
Striker edges sharp	38.1	36.8	45.0	39.1
Striker edges sharp and cracked	37.5	30.6	32.3	34.0
Normal striker, 2 scoops RDX (70 mg)	49.2	40.0	47.5	42.0

TABLE III
THE EFFECT OF THE AMOUNT OF EXPLOSIVE TESTED IN DESIGN NO. 1
The Probabilities of Explosion in 20 Trials are Within the Table

Drop- Height (Cm.) of 5 Kg. Hammer	20 mg. Charges		30 mg. Charges		40 mg. Charges		60 mg. Charges		80 mg. Charges	
	PETN	RDX	PETN	RDX	PETN	RDX	PETN	RDX	PETN	RDX
15	.125									
20	.487	.05	.25	.05	.20	0	0			
25	.50									
30	.53	.25	.423	.15	.30	.15	0	.35	.10	
35	.60									
40	.823	.60	.80	.45	.35	.30	.05	.525	.15	.675
50	.923	.85	.85	.50	.45	.45	.225	.70	.40	.15
60		1.00		.85	.65	.75	.65	.85	.80	.35
70				.95	.95	.95	.75		.90	.80
80							.90			.90
90							.95			

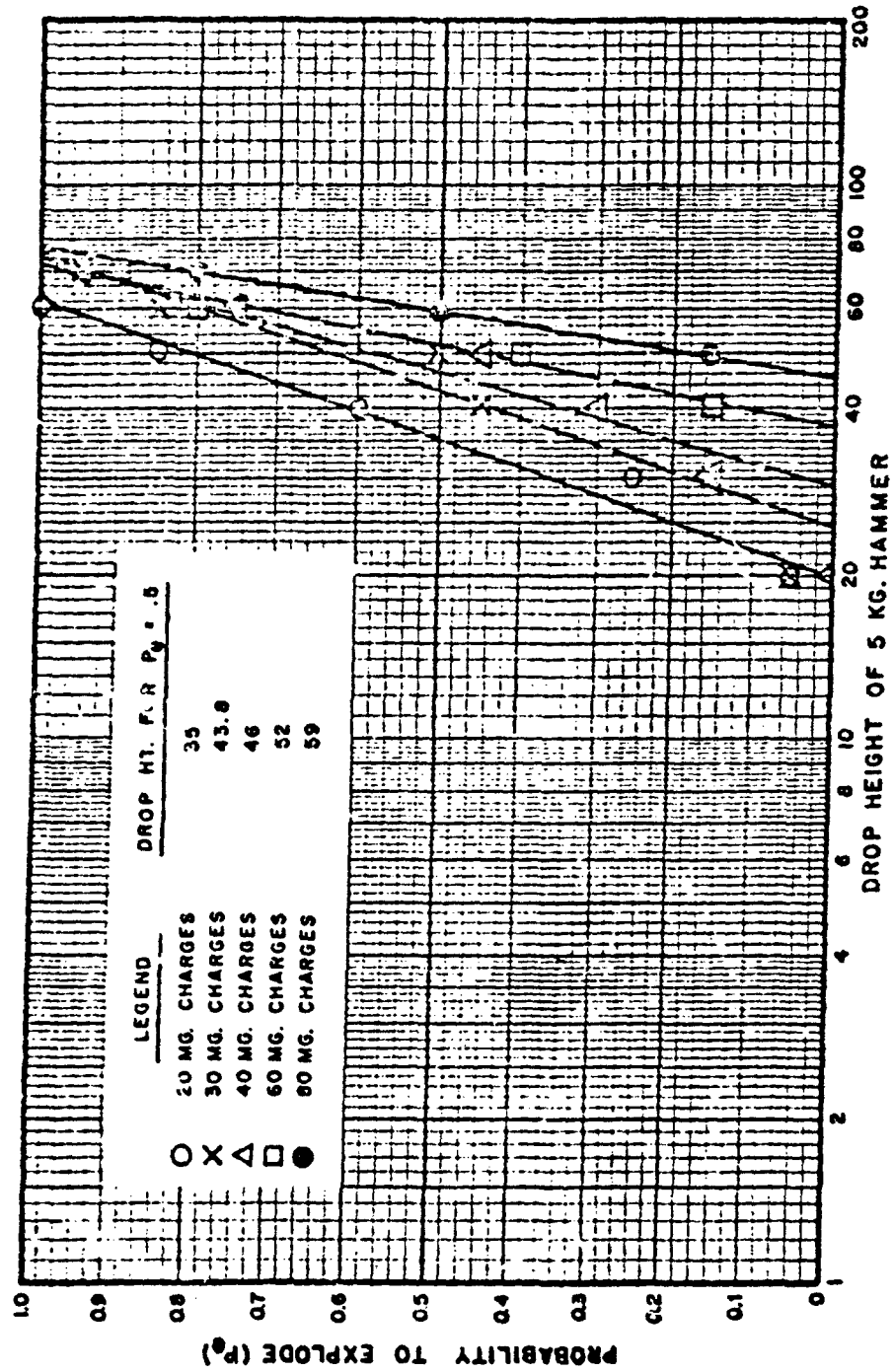
440 Trials



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FIG. 7 COMPARATIVE SENSITIVITIES OF PETN CHARGES OF VARIED WEIGHT



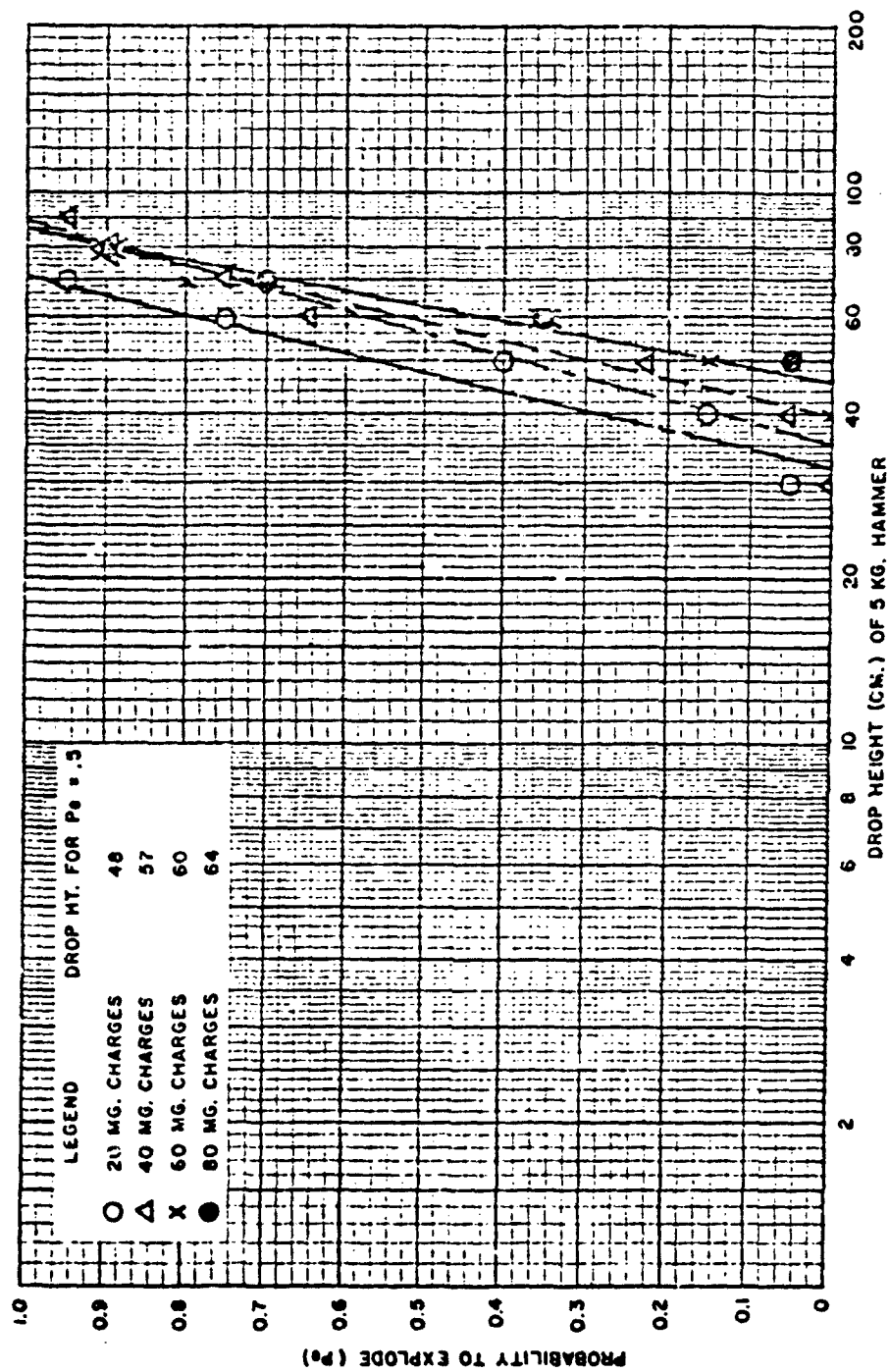


FIG. 9 COMPARATIVE SENSITIVITIES OF TETRYL CHARGES OF VARIED WEIGHT

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Figure 10 shows the 50% explosion height as a function of the amount of material tested for PETN, RDX and Tetryl on a log-log plot. PETN data with a 2 kilogram hammer are also shown and each point for this curve is the average of two Bruceton Method "runs" using the indicated charge weights. It is of interest to note that as the weight of charge approaches zero the 50% explosion height becomes independent of the mass of the hammer. This is in agreement with Koski and Lawrence (22).

Various mixtures of RDX and PETN were investigated by the No. 3 Design and the 50% explosion heights obtained. These data are summarized in Table IV and graphed in Figure 11, with the 50% explosion height as a function of the PETN content. The relationship is linear, as expected. The PETN used at the time of this study possessed very fine crystals and was more sensitive than more recent material. This phenomenon is likewise in agreement with Lawrence (ibid.) in that the finely divided PETN consisting of agglomerates was found to be more sensitive than material of a coarser nature.

TABLE IV

SUMMARY OF 50% EXPLOSION HEIGHTS FOR RDX-PETN MIXTURES AS
TESTED BY BRUCETON DESIGN NO. 3

% PETN	%RDX	"Run" I	"Run" II	Ave. 50% Explosion Ht.	
				Actual	Rounded*
0	100	51.4	54.0	52.7	53
10	90	43.8	50.0	46.9	47
20	80	40.0	40.8	40.4	40
30	70	43.3	48.3	45.8	46
40	60	36.6	36.1	36.3	36
50	50	36.9	38.4	37.6	38
60	40	21.9	40.9	31.4	31
70	30	24.4	20.9	22.6	23
80	20	21.8	21.5	21.6	22
90	10	21.9	25.6	23.7	24
100	0	17.9	16.5	17.2	17

*Used in Plot

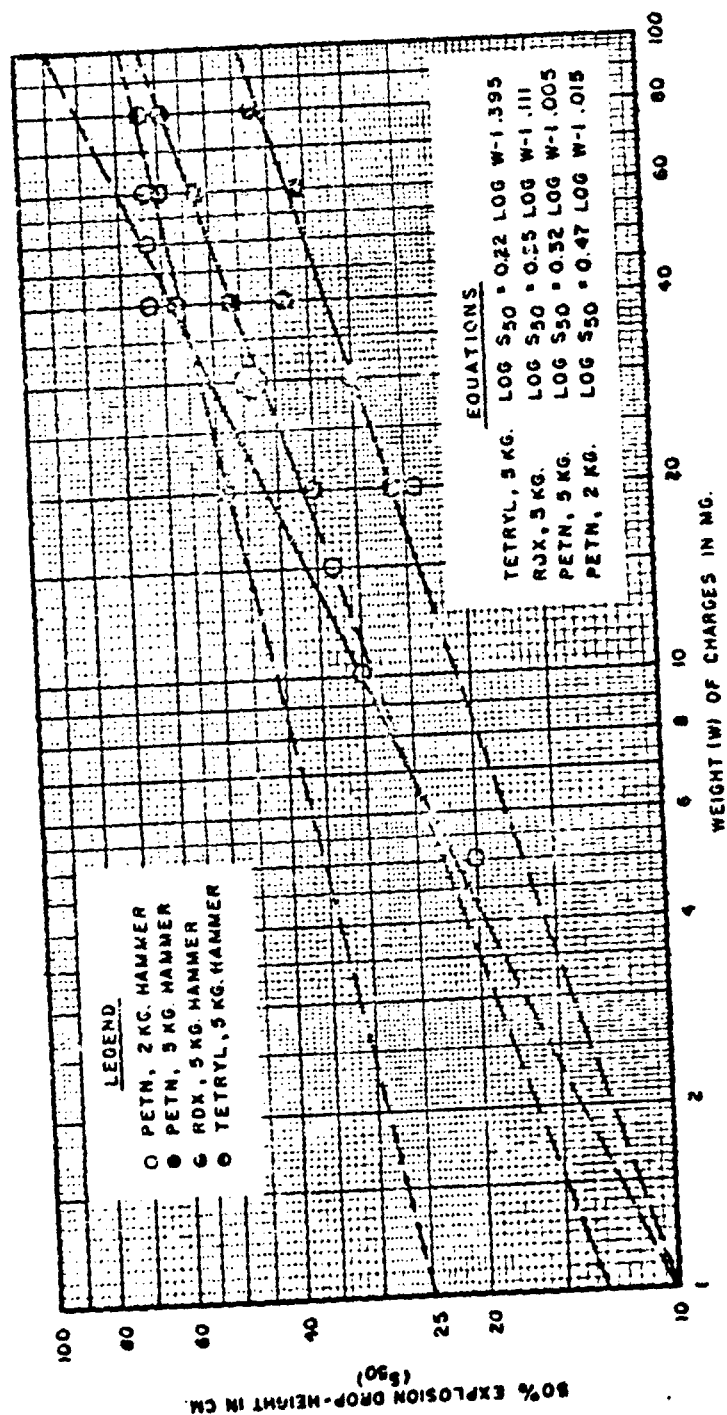


FIG. 10 S_{50} AS A FUNCTION OF WEIGHT OF CHARGE TESTED FOR PETN, RDX, AND TETRYL BY DESIGN NO. 3

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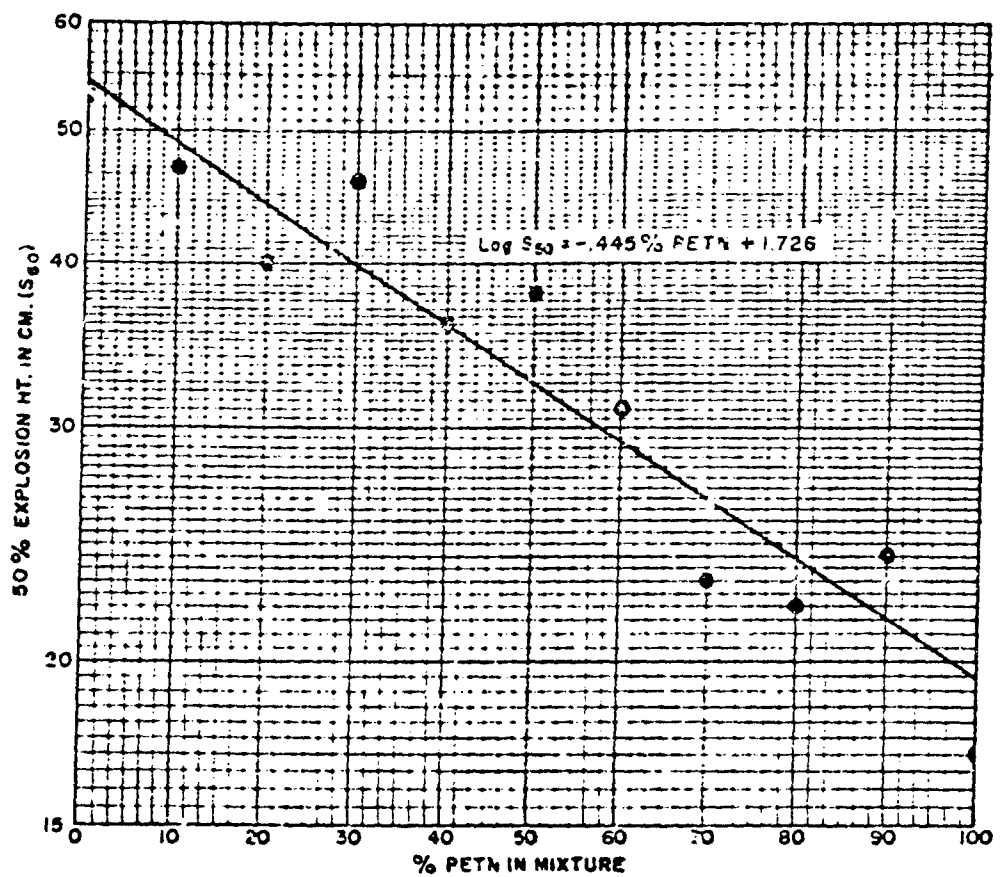


FIG. II 50% EXPLOSION HEIGHTS OF RDX-PETN
MIXTURES AS TESTED BY DESIGN NO. 3

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The Bruceton No. 1 Design

Perhaps the most common method of testing the behavior of explosives to impact is this particular design. It consists essentially of a 1/2" diameter ketos steel striker of 3" length with the anvil being the same as the No. 3. Plates II (S-1, A-1) and III (H-1) illustrate this design. The charge of explosive is merely centered on the anvil and the striker placed atop the charge to be in position for receiving impact. The design is fairly satisfactory for brisant explosives, but is not suitable for materials of soft, waxy consistency such as Tetryl, TNT, Composition B, Fivonite, Emmet and TNT mixtures. The main difficulty is the escape of the material during the impact process.

Table V and Figure 12 present data by conventional procedure for the behavior of RDX, PETN and EDNA as tested by Design No. 1. The erratic behavior of even these fundamental explosives is easily observed here.

Recently the sensitivity of nitrocellulose samples of varied nitrogen content was studied using design No. 1. These data are seen in Table VI in which the probabilities of explosion in 20 trials for different drop-heights are listed. From these data it is evident that sensitivity is not a function of nitrogen content when studied by Design No. 1. Several of these nitrocelluloses were bulky in nature and these erratic elastic properties undoubtedly contributed to results obtained.

TABLE V

SUMMARY OF DESIGN NO. 1 DATA BY CONVENTIONAL PROCEDURE
AND LARGE IMPACT MACHINE

Drop-Height (Cm.)	EDNA		EDNA*		PETN		RDX	
	Trials	P _e	Trials	P _e	Trials	P _e	Trials	P _e
15	20	0						
20	20	.175			20	.65	20	.20
25	20	0						
30								
40					20	.55	20	.45
50	40	.275						

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TABLE V (cont'd)

SUMMARY OF DESIGN NO. 1 DATA BY CONVENTIONAL PROCEDURE
AND LARGE IMPACT MACHINE

Drop-Height (Cm.)	<u>EDNA</u>		<u>EDNA*</u>		<u>PETN</u>		<u>RDX</u>	
	<u>Trials</u>	<u>P_e</u>	<u>Trials</u>	<u>P_e</u>	<u>Trials</u>	<u>P_e</u>	<u>Trials</u>	<u>P_e</u>
60	20	.30			20	.65	20	.65
70	40	.55						
80					20	.90	20	.45
90	60	.43						
100					20	.60	20	.45
120	20	.30	20	.35				
150	20	.20	20	.35	20	.90	20	.85
180	20	.30	20	.40				
200					20	1.00	20	1.00
210	20	.25	20	.35				
240			20	.50				
270			20	.40				
300			20	.40				
330			20	.45				

*Data with 2.5 Kg. Hammer

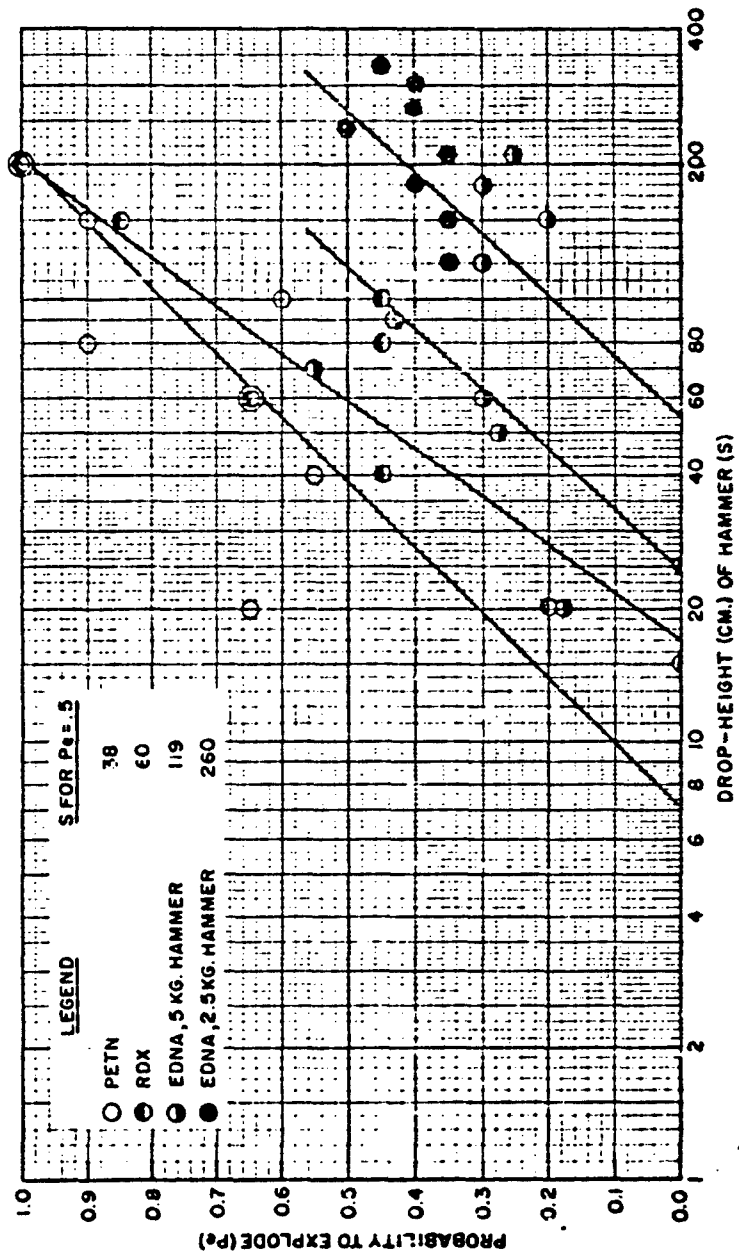


FIG. 12 COMPARATIVE SENSITIVITIES OF PETN, RDX AND EDNA BY DESIGN NO.1

TABLE VI
EXPLOSION PROBABILITIES OF NITROCELLULOSE OF VARIED NITROGEN
CONTENT AS INVESTIGATED BY DESIGN NO. 1

%Nitrogen in N.C.	Drop-Height (Cm.) of 5 Kg. Hammer													
	2	4	6	8	10	15	20	25	30	35	40	50	60	70
11.5				0	.15	.575	.85	.95	1.0					
11.9		0	.05	.35	.20	.40	.75	.95	.50*		.20*			
12.2				0	.45	.30	.65	1.00						
12.4		0	.10	.15	.15	.15	.05	.15	.20	.35	.40	.70	.917	1.0
12.6				0	.20	.30	.45	1.0						
13.1	0	.10	.10	.20	.30	.55	.60	.90	1.0					
13.54				0	.10	.45	.50	.40	1.0					

*10 Trials

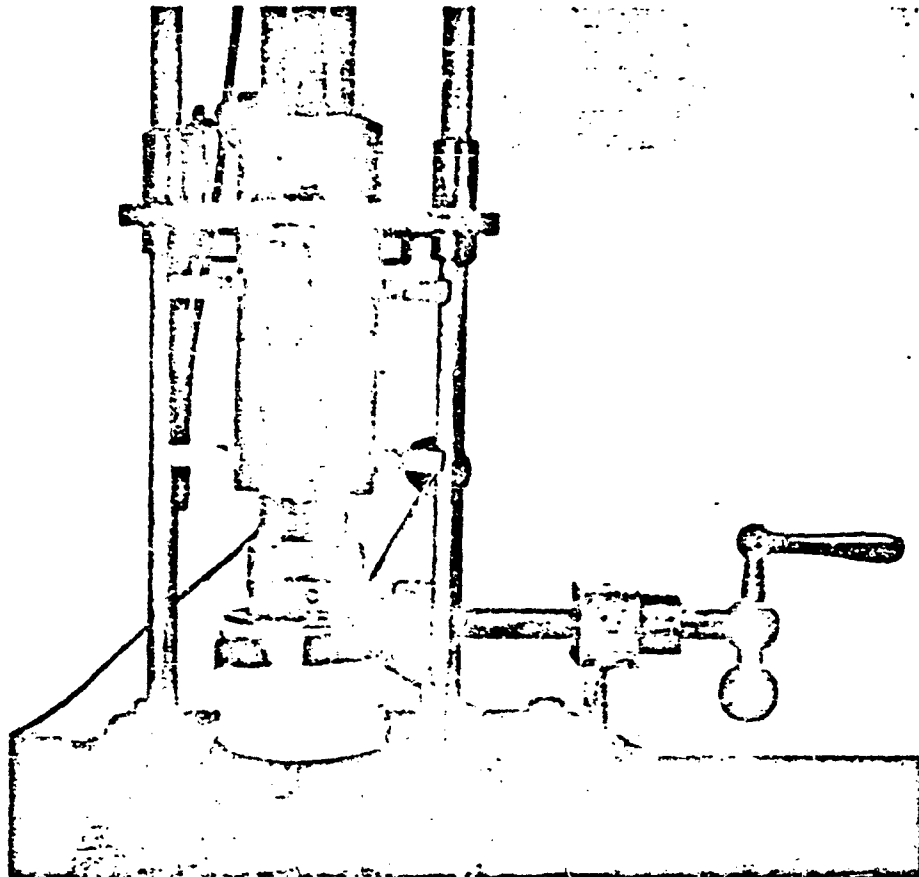
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The No. 5 Design

During 1941-42 and part of 1943 a method designated as No. 5 was used to study explosives which failed to show a 50% explosion drop-height when tested by designs No. 1 and No. 3. The anvil (Plate II, labeled A-5) consisted of a 1 1/4" diameter ketos steel cylinder of 2 1/2" height with a central cavity or depression of 3/8" diameter and 1/16" depth. The cavity served to contain a 30 mg. charge of explosive, which was in turn covered with one ply tin foil of 0.0005" thickness. A tapered striker (Plate II, S-5) was then forced atop the explosive. The result was a snug fit, as the foil acted as a seal and gave a high confinement. Because of the localized confinement, this design proved capable of detonating most explosives whether in solid or liquid forms. Plates IV and V illustrate the apparatus for testing explosives in molten form. It was by this test that molten TNT showed appreciable sensitiveness. Other solid explosives were likewise found to be more sensitive as the melting point was approached and exceeded. These interesting data are seen in Table VII. Figure 13 serves to show the 50% explosion drop-height of TNT as a function of temperature. From the graph it is seen that the 50% explosion height changes from 60 at room temperature to 16-17 cm. at the melting point of TNT.

Composition B, Pentolite (50/50) and TNT were recently tested at varied temperatures with different sets of No. 5 strikers and anvils. The striker-anvil depression clearances appeared identical, but results of Table VIII indicate differences. Notice the deviation between two runs of Pentolite on different anvils; and that TNT behaved erratically at room temperature, as the usual 50% explosion drop-height is 45-55 cm. Molten explosive values of Table VIII likewise are not in agreement with those of Table VII.

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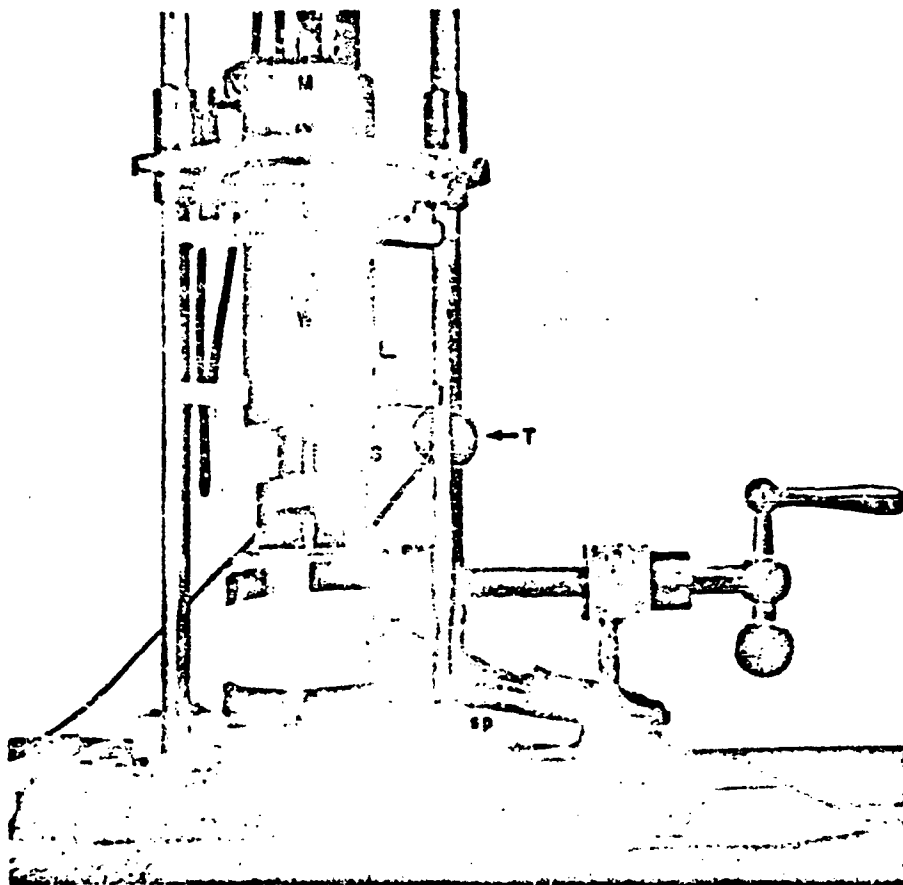
A CHARGE OF UNMELTED EXPLOSIVE IS READY TO BE COVERED WITH ONE PLY OF TIN FOIL. C INDICATES CHARGE CENTERED IN ANVIL DEPRESSION.

PLATE IV
THE NO.5 DESIGN AS USED FOR EXPLOSIVES IN MOLTEN FORM

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S = STRIKER

W = 5.0 KILOGRAM DROP-HAMMER ATTACHED TO M OR ELECTROMAGNET

T = THERMOMETER

SP = SMALL SPOON OR SCOOP USED TO MEASURE EACH CHARGE OF EXPLOSIVE

PLATE V
THE NO. 5 DESIGN WITH STRIKER IN POSITION FOR IMPACT

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TABLE VII
SUMMARY OF SENSITIVITY DATA FOR EXPLOSIVES IN MOLTEN STATE

Explosive	Temp. °C	50% Explosion Heights					Ave.	Rounded
		Run I	Run II	Run III	Run IV	Run V		
TNT	30	62.1	76.7	51.0	52.6	57.1	59.9	60
TNT	50	61.2	54.0	55.8	52.5		55.9	56
TNT	70	45.0	43.0	42.5	40.0		42.6	43
TNT	75	38.0	36.0	35.0			36.3	36
TNT	85	12.0	11.2	12.0			11.7	12
TNT	90	15.8	13.6	12.2	7.8		12.7	13
TNT	110	14.2	7.8	7.8	5.0		8.7	9
TNT	130	19.0	5.5	3.7	3.0		7.8	8
TNT	20	22.5						
Picric Acid	125-135	10.0						
Picric Acid	20	25.0						
Composition B	80-95°	13.0						
Composition B	20	31.7	32.1					
50/50 Pentolite	95-100	10.0						
50/50 Pentolite	50	59						
Emmet	40	54						
Emmet	60	10						
Emmet								
2-Methyl-2-nitro-propandiol-1, 3-dinitrate	30	43						
2-Methyl-2-nitro-propandiol-1, 3-dinitrate	50	4						

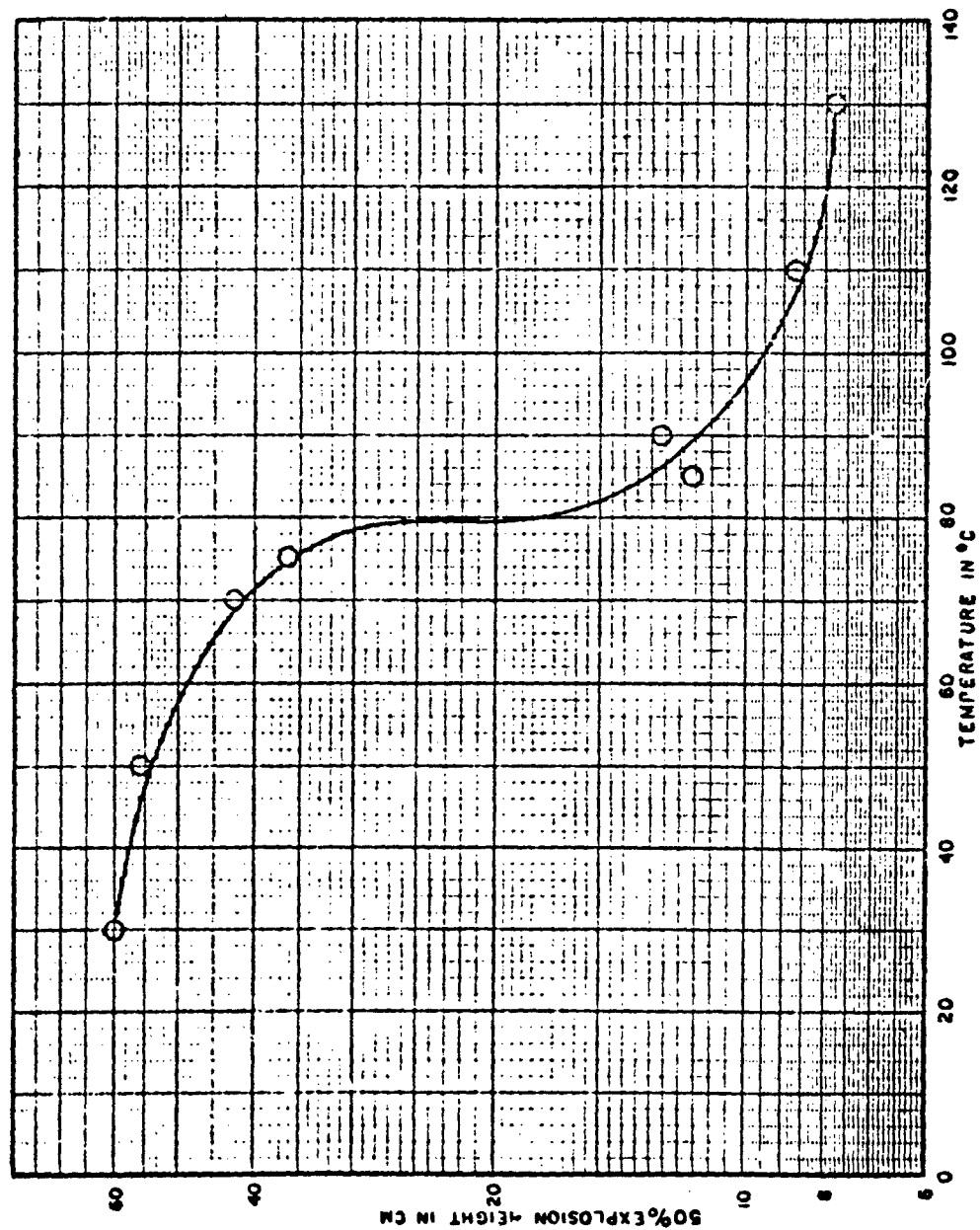


FIG. 13 SENSITIVITY OF TNT AS A FUNCTION OF TEMPERATURE
AS TESTED BY DESIGN NO. 5

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TABLE VIII

FURTHER DATA AT ELEVATED TEMPERATURES WITH DESIGN NO. 5
(Values are 50% Explosion Heights in Cm)

<u>Explosive</u>	<u>20-25°C</u>	<u>95-100°C</u>	<u>108°C</u>	<u>121°C</u>
Composition B	26.0		23.4	25.8
Composition B	28.6			
50/50 Pentolite	31.7	52.6		
50/50 Pentolite	32.1	10.0		
TNT	>90		20.8	17.0

Liquid TNT was studied more extensively by the conventional procedure of numerous trials at each drop-height using design 5. Comparative results with 80/20 nitroglycerin-dimethyl phthalate are shown in Table IX and Figure 14. The nitroglycerin-phthalate mixture produced complete detonations in most cases, while the TNT explosions were of a partial nature.

Attempts to explode liquid TNT by design No. 3 indicated the material was not sensitive. Ten trials at 10-90 cm. (10 cm. increments) were for each height all failures. Much of the liquid was squeezed out around the striker during the impact process, which was most likely a factor in that no explosions resulted.

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TABLE IX

COMPARATIVE DATA BY DESIGN NO. 5 FOR TNT AT 85-90°C
AND 80/20 NITROGLYCERIN-DIMETHYL PHTHALATE
AT ROOM TEMPERATURE

<u>Drop-Height of 5 Kg. Hammer</u>	<u>Molten TNT</u>		<u>80/20 NG-Phthalate</u>	
	<u>Trials</u>	<u>Ave. P_e</u>	<u>Trials</u>	<u>Ave. P_e</u>
4	20	0		
6	20	.025		
8	40	.237	20	0
10	40	.325	40	.187
15	40	.537	40	.625
20	60	.40	40	1.0
30	20	.475		
35	20	.30		
40	20	.70		

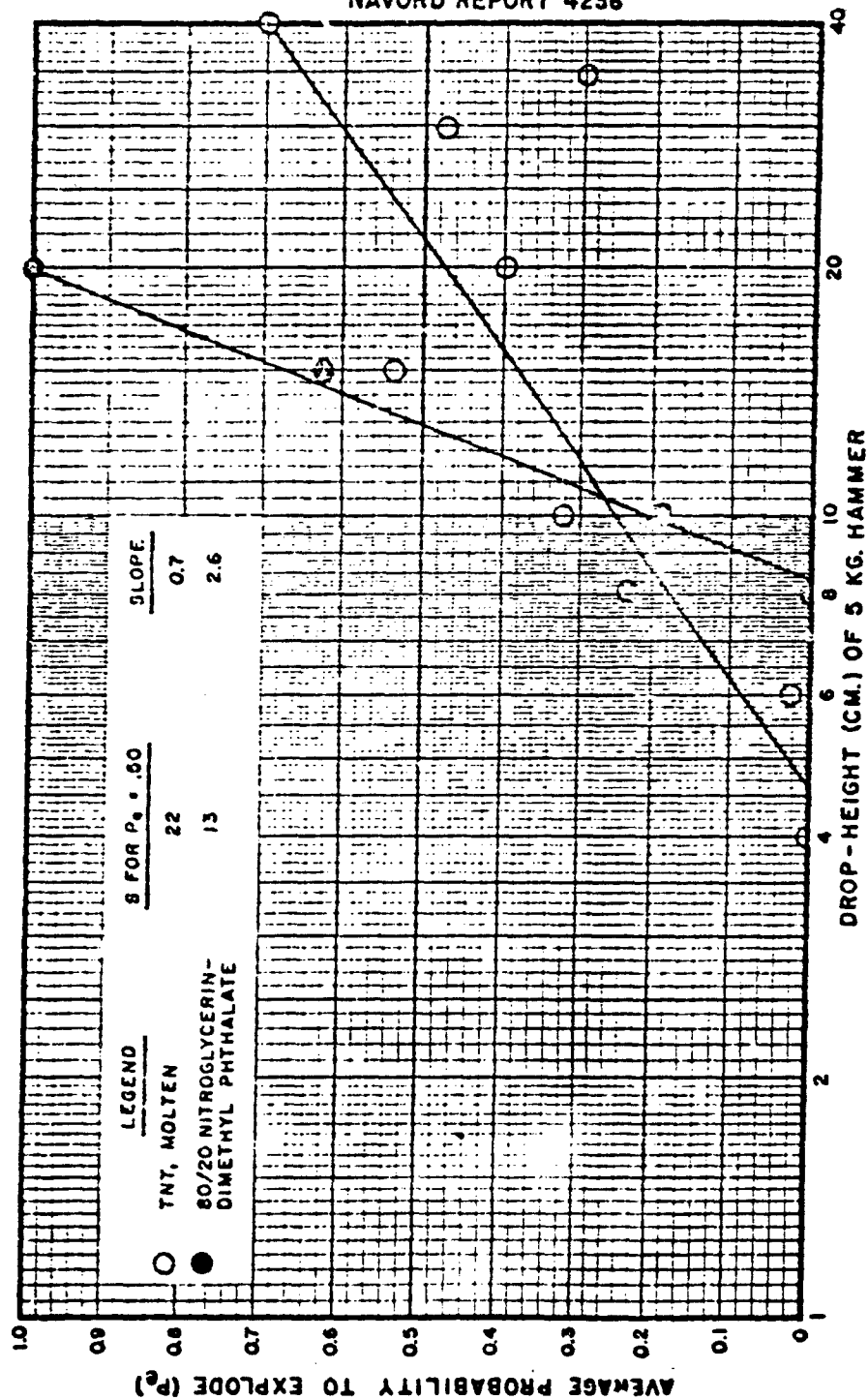


FIG. 14 COMPARATIVE SENSITIVITIES OF MOLTEN TNT AND 80/20 NG-DIMETHYL PHTHALATE AS TESTED BY DESIGN NO. 5

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A study of the behavior of Cordite and Ballistite to impact by Designs No. 1 and No. 5 was carried out in September, 1942. It was found that both propellants became sensitive when the particle size approached thin shavings in form. When tested at elevated temperatures by the No. 5 design, Cordite was seen to explode furiously at very low drop-heights. The explosions were actually near-detonations in intensity. Table X shows 50% explosion heights by Design No. 1 as a function of particle size, while Table XI indicates drop-heights for explosion probability of 0.5 for Cordite as tested by design No. 5 at elevated temperatures. The heated Cordite was in the form of single pieces $1/4 \times 1/4 \times 1/16$ " in dimensions. A 5.0 kilogram drop-hammer was used throughout these studies.

TABLE X

**THE EFFECT OF THE PARTICLE NATURE ON THE SENSITIVITY
OF CORDITES AND BALLISTITE, AS STUDIED BY DESIGN NO. 1**

Nature of Material	<u>British Type Cordite</u>	<u>British Rocket Cordite</u>	<u>U. S. Navy Ballistite</u>
Single piece, $1/4 \times 1/4 \times 1/16$ "	53.0	52.6	29.2
8-10 pieces, $3 \times 2 \times 1$ mm.	40.0*	26.1	17.4
Shavings (30-40) $1 \times 1 \times 1$ mm.	37.5**	18.1	

*60°C

**75°C

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TABLE XI

THE EFFECT OF ELEVATED TEMPERATURES ON THE BEHAVIOR OF
BRITISH CORDITE TO IMPACT

<u>Temp.</u> <u>°C.</u>	<u>Design</u> <u>No. 5</u>	<u>Design</u> <u>No. 5*</u>	<u>Design</u> <u>No. 1</u>	<u>Remarks</u>
20	15.8	20.7	53.0	*No tin foil
60	10.8	12.6	40.0	covering
75	10.0	13.6	37.5	
140	10.0	10.8		**Ballistite
175	3.3	3.5		
175	2.2**			

By experience, it was found that the clearance between the striker and the anvil depression was most important for the No. 5 design. Results were irreproducible unless 0.001" clearance could be maintained during testing. Maintenance of such clearances proved to be very difficult and the design was practically discontinued in 1943.

During the course of two years, many explosives were examined as to impact behavior. Table XII lists in summary form the 50% explosion drop-heights for common and newer substances as investigated by designs No. 3 and No. 5. Unless indicated, the values are the result of one "run" by the Bruceton Method.

During the period October, 1942 until May, 1943, time was devoted in search of a method of impact testing which would be suitable for the study of the TNT class of explosives. This period saw the development and discontinuation of designs 7, 8, 9 and 10. These and subsequent designs (11, 12, 13) involved the use of the large impact machine at Bruceton.

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TABLE XII

COMPARATIVE SENSITIVITIES (50% EXPLOSION DROP-HEIGHTS) BY
DESIGNS NO. 3 and NO. 5

Chemical Name of Explosive	Common Designation	No. 3	No. 5
Lactitol Decanitate		1.5	--
Mannitol Hexanitate	Nitromannite	8	8
Dulcitol Hexanitate	Nitrodulcite	11	--
Lead Trinitroresorcinate	Lead Styphnate	11	--
Starch Nitrate	Nitrostarch	12	--
1-Guanyl-4-nitrosamino- guanyltetrazene	Tetracene	12	--
	Blasting Gelatin	16	--
Lead Azide	Lead Azide	19	--
Pentaerythritol Tetra- nitrate**	PETN	22	8
2, 5-Dinitro-2, 5-bis(hydroxy- methyl-1, 6 hexanediol Tetranitrate		22	--
β (N-nitroguanyl)ethyl Nitrate		24	27
Diethanolnitramine	DINA	27	--
Pentaerythritol Tetra- nitrate	PETN	29	--
Tetramethylolcyclohexanol Pentanitate	Fivolite	29	--
Ethylenedinitramine	EDNA	30-40	35
Cyclotrimethylene Tri- nitramine	Cyclonite, Canadian		
Erithritol Tetranitrate	ETN	38	--
β (2, 4, 6-trinitrophenyl- nitramine)Ethyl Nitrate	Pentryl	42	--
Dinitroxyethylnitroxamide	NENO	42	--
Cyclotrimethylene Tri- nitramine	Cyclonite, U.S. - British	48	23

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TABLE XII (cont'd)

COMPARATIVE SENSITIVITIES (50% EXPLOSION DROP-HEIGHTS) BY
DESIGNS NO. 3 and NO. 5

Chemical Name of Explosive	Common Designation	No. 3	No. 5
Ammonium Perchlorate	Ammonium Perchlorate	55	46
2, 4, 6- Trinitrophenyl- methylnitramine	Tetryl	56	20
2, 6-Dinitro-2, 6 bishydroxy- methyl-1, 7 heptanediol tetranitrate		82	--
	Baranal	84	--
	Torpex-II	86	--
	Torpex-I	88	--
Ammonium Picrate	Explosive D	80	19
2, 4, 6- Trinitrophenol	Picric Acid	>90	22
N-nitro-n-Methylhydroxy- acetamide Nitrate	Hyman	>90	24
2-Methyl 3, 3, 3 Trinitro- butane	--	>90	24
Tetramethylolcyclo- hexanone Tetranitrate	Sixonite	>90	29
2, 4, 6 Trinitrobenzene	TNB	>90	29
2-Methyl-2-Nitro-1, 3- Propanediol Dinitrate	Nitroisobutylglycol Dinitrate	>90	37
Tetramethylolcyclo- pentanone Tetranitrate	Fivonite	>90	38
N, N' -dimethyl-N, N'dinitro- oxyamide	MNO	>90	39
3-Methyl 2, 2, 3 Trinitro- pentane	--	>90	46
2, 4, 6 Trinitrophenol	TNT	>90	48
"	Sublimed TNT	>90	50
Ethylenediamine Dinitrate	--	>90	52
2, 4, 6 Trinitrophenol	TNA	>90	55
2, 4 Dinitrobenzene	DNB	>90	58
2, 4 Dinitrotoluene	DNT	>90	58

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TABLE XII (cont'd)
COMPARATIVE SENSITIVITIES (50% EXPLOSION DROP-HEIGHTS) BY
DESIGNS NO. 3 and NO. 5

Chemical Name of Explosive	Common Designation	No. 3	No. 5
Ethyltrimethylolmethane Trinitrate	Emmet	>90	58
2, 3, 3 Trinitro-2, 2 Methyl- butane	--	>90	70
2, 4 Dinitroaniline	DNA	>90	85
Urea Nitrate	Urea Nitrate	>90	85
2, 4 Dinitrophenol	DNP	>90	97
Nitrourea	Nitrourea	>90	>100
Hexamethylene tetramine Dinitrate	Hexamine Dinitrate	>90	>100
3-Ethyl-2, 2, 3 Trinitro- pentane	--	>90	--
Nitromethane	Nitromethane	--	80
Tetranitromethane	Tetranitromethane	--	83
Diethyleneglycol Dinitrate*	DEGN	--	2-3
Glyceryl Trinitrate*	Nitroglycerin	--	3.0
	Blasting Gelatin	--	3.2
Sorbitol Hexanitate*	Nitrosorbitan	--	7
Mannitol Hexanitate*	Nitromannite	--	9
Glyceryl Lactate Tri- nitrate	CLTN	--	9
Butine-2 diol-1, 4 Di- nitrate	--	--	9
Methyltrimethylolmethane Trinitrate	Memmet	--	17
Dinitrophenol Sulfone	--	>90	>100
N, N'-Dinitropiperazine	--	>90	>100

* 2 Kilogram Hammer

** Agglomerated PETN

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The No. 7 Design

In principle, this design was a modification of the No. 3. Since strikers with the No. 3 showed a tendency to bulge and develop cracked edges from drop-heights exceeding 90 cm. with a 5.0 kilogram drop-hammer, it was reasoned that a larger striker with larger cups would eliminate this difficulty. A 1/2" diameter ketos drill rod tapered to 0.445 ± 0.001 " to fit a copper cup was the result. Plate II illustrates the striker (S-7), copper cups (C-7) and anvil (A-7) used in this design. Experience proved that copper was the improper material for the cups, as it tended to flow from the impact shock. Explosives possessing soft crystals were able to escape most of the impact energy by creeping into the space between the cup wall and striker. Results in general proved to be erratic and were definitely a function of the amount of explosive tested in addition to the diameter of the striker. The design was discontinued for these reasons in February, 1943. Table XIII shows a summary of 50% explosion drop-heights of several Bruceton runs on common explosives. A few runs were made with one ply tin foil covering the sample, and these are likewise shown in Table XIII.

It is possible that a heavy walled steel cup fitting a 1/2" diameter striker may eliminate the main disadvantage of the No. 7 design. Another possibility is a small metal disc covering the explosive which in turn rests atop a similar disc of abrasive paper. Investigations along this line have not as yet been pursued.

The No. 8 Design

Design 8 was a combination of designs No. 1 and No. 3. An explosive-containing brass cup was centered under a 1/2" diameter striker and the drop-hammer released to smash the cup. This procedure was seen to detonate, with a loud report, even the TNT class of explosives. Results appeared reproducible early in the study, but deviations did occur as more data were obtained. Variations in the hardness of the brass cups and in the technique of centering a loaded cup under the striker were factors causing deviations. Tables XIV and XV summarize the 50% explosion drop-heights of common explosives examined. Note that the order of sensitiveness is altered when a 2.5 kilogram drop-hammer is used. The design saw usage during October - December, 1942, and was then discontinued.

TABLE XIII
COMPARATIVE DATA BY DESIGN NO. 7

COMPARATIVE DATA BY DESIGN NO.												2.5 Kg. Weight	
Explosive	5 Kilo. Weight										One ply tin foil		
	BRUCETON RUN NO.										1	2	Ave.
	1	2	3	4	5	6	7	8	9	10			
Nitroglycerin	6.3	3.2	10.7								6.7		
Nitromannite	28										28		
Mercury	55										55		82
Fulminate	64	45	53								54	82	82
PETN	87										87	67	67
13% Pentolite	146	86	107	55	78						95	133	133
Tetryl	114	117									116		
RDX													
U.S. Com- position A	127	150	151								142		
Composition B	146										146		
TNT	155	162	190	200	188	121	130	99	120	164	153	163	131
Picric Acid	183	170	150	148							163	100	100
British											167		
Comp A	167												
Ammonium												264	264
Picrate	286										286		
Nitroguanidine	>337										>337		
Ammonium													
Nitrate	>337										>337		

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TABLE XIV
COMPARATIVE DATA OBTAINED BY DESIGN NO. 8 WITH A 5 KILOGRAM WEIGHT

Explosive	BRUCETON RUN NO.														Ave.
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	
PETN	35	50	34	39	51										42
Tetryl	39	51													45
RDX	33	36	57	43	47	46	47	58	56						47
Picric Acid	94	98	123	115	86	100	100	76							99
Ammonium Picrate	106	166	110	85	109	82	101	98							107
TNT	106	107	116	118	108	117	105	120	118	124	110	89	101		110

TABLE XV
COMPARATIVE DATA OBTAINED BY DESIGN NO. 8 WITH A 2.5 KILOGRAM WEIGHT

Explosive	BRUCETON RUN NO.														Ave.
	1	2	3	4	5	6	7	8							
RDX	81	78	86	72											79
Tetryl	87														87
Picric Acid	119	112	115	142											122
TNT	185	176	180	185	186	184	203	196							186
Ammonium Picrate	186	182	268	260	160										211

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The No. 9 Design

This method was studied during February-May, 1942. Conditions were essentially those of a modified No. 8 design. The difference was that a steel cup, similar in shape and dimensions to the brass cups, was flattened into the form of a disc prior to using. The disc was prepared by resting a 1/2" striker atop the steel cup, and smashing the cup by a 105 cm. drop of the 5.0 kilogram hammer. The resulting disc possessed a crater into which a small charge of explosive could be placed. It was thought that if explosive could be entrapped (during impact) under the overlapping edge of the disc, a good detonation should result from exceptional confinement. It was also reasoned that the dissipation of energy, as in design 8, should be reduced materially as most of the smashing was completed in preparation of the discs.

Unfortunately, observations indicated that the prepared discs were not uniform in thickness or depression depth. Twenty discs were measured with a micrometer for thickness and crater depth both before and after a run with TNT as the explosive. These measurements are listed in summary form in Table XVI, where deviations are easily seen, particularly in column 4. Table XVII summarizes 50% explosion drop-heights on explosives studied.

Lead azide and lead styphnate displayed very peculiar behavior when tested by the No. 9 design. Both substances are normally quite sensitive, but appeared decidedly insensitive by method 9. These materials tended to be compressed into a disc of the exact shape as the crater within the steel disc, and were able to escape most of the impact energy. Mobility of the explosive to the confining space under the edges of the disc did not occur with these salts on trials registering failure to explode. The likely reason for this behavior is strange elastic properties of these particular substances. The design was discontinued in May, 1942 because of uncontrollable deviations of the steel discs.

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TABLE XVI

SUMMARY OF STEEL DISC MEASUREMENTS IN CONNECTION WITH
DESIGN 9

(Dimension values are $\times 10^{-3}$ in.)

Thickness of Disc Edge before Impact	Thickness of Disc Edge after Impact	Change in Disc Edge Thickness from Impact	Depth of Crater before Impact	Depth of Crater after Impact	Change in Depth of Crater from Impact	Drop-Height (Cm.) of 2.5 Kilogram Hammer	Result of Trail
25.9	16.8	9.1	5.4	1.0	-4.4	205	E
24.9	16.4	8.5	3.1	1.6	-1.5	190	E ₁
25.1	19.3	5.8	3.9	4.5	+0.6	175	E
25.0	19.7	5.3	2.8	4.9	+2.1	160	N
25.7	20.6	5.1	4.5	5.4	+0.9	175	N
24.3	17.9	6.4	3.1	3.7	+0.6	190	N
25.7	19.9	5.8	4.1	4.7	+0.6	205	N
25.6	16.5	9.1	2.8	1.7	-1.1	220	E
25.3	18.9	6.4	3.3	4.1	+0.8	205	E
25.3	17.5	7.8	3.1	3.5	+0.4	190	E ₁
25.9	21.2	4.7	5.9	5.8	-0.1	175	N
25.7	18.4	7.3	4.7	3.2	-1.5	190	N
24.0	16.6	7.4	3.2	1.7	-1.5	205	E ₁
25.2	17.3	8.1	3.0	2.5	-0.5	190	E
26.0	19.3	6.7	4.2	5.9	+1.7	175	E _p
25.0	17.6	7.4	2.0	2.8	+0.8	160	N
26.9	18.4	8.5	6.5	2.0	-4.5	175	E ₁
26.5	20.6	5.9	4.3	4.1	-0.2	160	N
26.4	16.9	9.5	3.2	1.1	-2.1	175	N
27.1	18.3	8.8	5.3	3.1	-2.2	190	E

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TABLE XVII
SUMMARY OF 50% EXPLOSION HEIGHTS BY DESIGN NO. 9 (2.5 KILOGRAM HAMMER)

Explosive	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Ave.
Tetrazene	37														37
Mercury Fulminate	44														44
DNA	47														47
PEIN	65	65	67												66
Nitromannite	70														70
Silicite	120														120
Fivonite	121														121
EDNA	121														121
Lead Styphnate	121														121
Pentolite (50/50)	126	118	120	121	119										121
Exmet	124														124
Comp. A (duPont)	124	110	160												131
RDX	126	125	132	111	123	126	151	155	153	149	165	153	142	142	133
RDX	98	115	117	94	138	145									142
Composition B	142														142
Tetryl	118	137	139	145	133	153	148								143
Lead Azide	123	139	168												148
Pentolite, 13%	133	162													174
Picric Acid	132	154	183	201	190	186	169	177	171	192	193				191
Comp. A (British)	175	186	213												201
Trinitrobenzene	248	181	171	198	203	183									205
Sodium Picrate	205														205
TNT	184	157	156	183	185	158	190	200	213	194	201	258	228	235	209
TNT	237	233	246	226	190	196	182	178	182	178	205	210	195	196	234
Trinitrophenylene	234														234
Ammonium Picrate	302	322	272	307	337										308

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The No. 10 Design

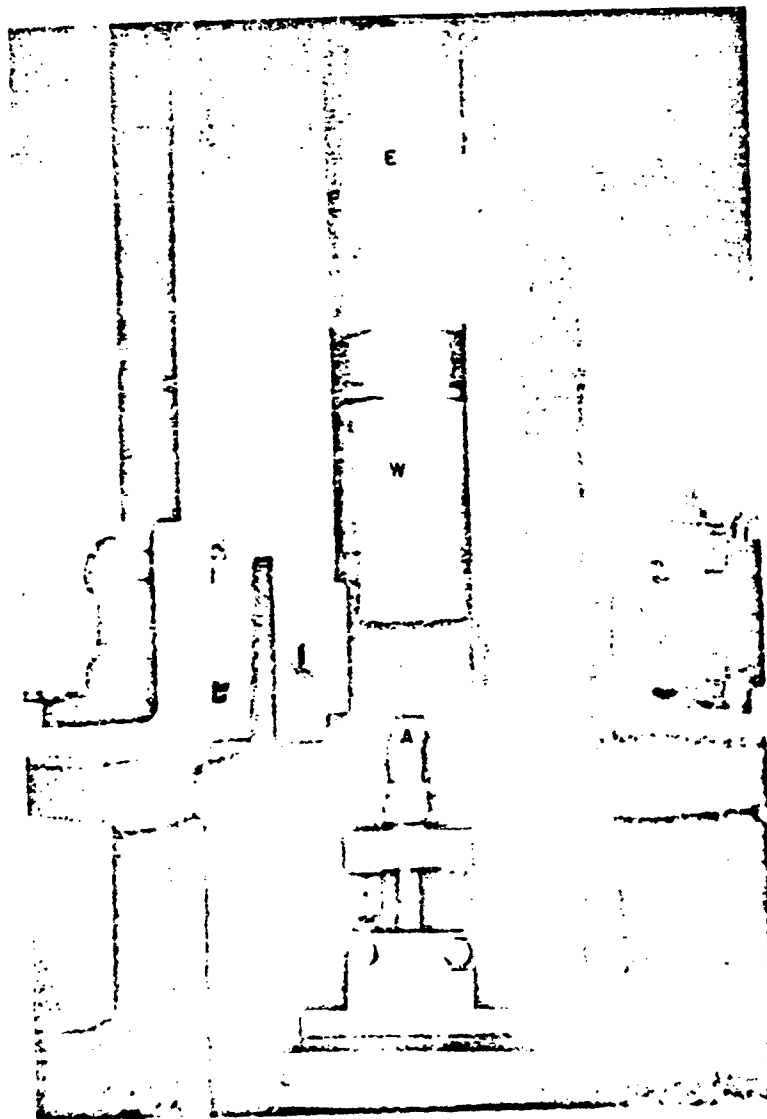
This method was used briefly during May, 1942. Conditions were a modification of Method No. 1. Instead of a 1/2" diameter striker, the 2.5 kilogram hammer itself became the striker. As seen in Plate VI, the striking area of the hammer was in reality a press fitted ketos steel anvil of 1 1/4" diameter surface. The 1 1/4" diameter gave the needed surface to prevent the escape of the explosive, as was the disadvantage with design No. 1. Another reason for the use of the hammer as striker was that the velocity of the hammer at impact is greater than that of an inserted striker, unless the weight of the striker is negligible in comparison with the drop-hammer. With a 1/2" striker of weight of 65 grams, the velocity difference is negligible, although present; however, with larger strikers weighing 500 grams such as the type for design 12b, this effect becomes more prominent. To insure the absence of the velocity difference was the other reason in mind while using the hammer as the striker.

Plate VI shows a general view of design 10. The charge of explosive was merely centered atop the elongated anvil and the hammer released from desired drop-heights. In some instances, liquid explosives in particular, the charge was covered with a single ply of 0.0005" (thickness) tin foil to prevent to a considerable degree the escape of the liquid during impact. A single drop from a common medicine dropper became the sample for liquid explosives. This amounted to 40-50 mg. of material, in the case of nitroglycerin. Explosions produced with liquids were most violent in nature, and the operator was compelled to use cotton ear plugs to endure the sound intensity.

Solid explosives were observed to behave erratically in the No. 10 test. The flushness of the impacting surfaces was the most important variable. A carbon paper imprint of the impact served to check the condition of the striking surfaces. Unsatisfactory surfaces were corrected by refacing in a lathe with grinding wheel attachment; however, this proved to be awkward and time consuming and it was decided to discontinue using the hammer as a striker.

Several solids were tested in the presence of sand blasted surfaces, but resulting explosions soon removed the grit effect and smooth, slippery surfaces again were the conditions. Table XVIII presents data from method 10.

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W - 2.5 KILOGRAM DROP-HAMMER
E - ELECTROMAGNETIC HOLDER FOR WEIGHT
A - ELONGATED ANVIL WITH PIN TO PREVENT ESCAPE OF
ANVIL DURING IMPACT

PLATE VI
GENERAL VIEW OF DESIGN NO. 10

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TABLE XVIII
COMPARATIVE 50% EXPLOSION HEIGHTS OBTAINED BY DESIGN 10
AND 2.5 KILOGRAM HAMMER

Explosive	Physical State	Tin Foil Covering	Sand Blasted Surfaces	Smooth Steel Surfaces	Remarks
Mercury Fulminate	Solid		21		
Lead Azide	"		35		
Hydroxyethyl Glycerol Trinitrate	Liquid	41			*Ave. of 51, 35
Nitroglycerin	"	43*			
Glycerol Monoglycollate Trinitrate	"	54			
PETN	Solid	60			
Tetryl	"	<60	125	110, 315*	*Non-flush surfaces
β -Nitroxyethylnitramine	Liquid	81			
Diethyleneglycol Dinitrate	"	98			
Glycerol Monolactate Trinitrate	"	100			
EDNA	Solid		133, 248*		*Non-flush surfaces
Ammonium Picrate	"	<100			
TNT	"		250		

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The No. 11 Design

The period May - August, 1943 resulted in the development of the eleventh in a series of Bruceton impact methods. The procedure presented a new approach to the sensitivity problem in that the explosive was rested upon a 1/2" square of abrasive surface before being subjected to impact. The abrasive surface was in the form of a square of 00 specification Armour flint paper, which has the following screen analyses as supplied by the Armour Sandpaper Company, Chicago, Illinois:

<u>Mesh of Screen</u>	<u>%</u>	<u>Size of Openings X 10⁻⁴ in.</u>	<u>Size of Openings (μ)</u>
on 125 mesh	6	42	107
on 157 mesh	76	33	84
Through 157 mesh	18	33	84
Through 180 mesh	5	25	63

The idea of the No. 11 design was suggested by Dr. D. P. MacDougall in hopes of obtaining reliable data for comparing a series of EDNA samples. EDNA was erratic in behavior with designs No. 1 and No. 3, and such a test as No. 11 was definitely needed. Design 11 was the same as No. 1 except that the sample was placed on a 1/2" square of abrasive paper before the striker was placed atop the charge. The hammer for most No. 11 data had a mass of 2.5 kilograms.

The design proved to be satisfactory for its original purpose of comparing EDNA samples. Results were reproducible in general, as a new square of flint paper was used in each trial to present a nearly constant surface. Strikers and anvils deteriorated in time and needed occasional resurfacing or refacing. The anvils showed more deterioration as a 1/2" diameter circular area possessing scratches and pits became apparent after 500 trials. Strikers with scratched surfaces did not affect results, however.

Physical difficulties were encountered with the No. 11 technique in the case of drop-heights >100 cm. for explosives of soft, waxy

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consistency. Such materials as TNT, Composition A, Composition B, and 50/50 Ednatol behave normally until the drop-height becomes >100 cm. At these heights, explosions are difficult to identify and 100% explosion points are not obtained during the conventional method of testing.

There are several possible reasons for this behavior. It was thought, at first, that the heat produced from the impact of steel on flint crystals was melting TNT (the explosive which first displayed the above effect); which in turn was forced to flow past the flint crystals and become absorbed in the paper base and form an insensitive TNT-paper mixture. This hypothesis was supported by the following: for all trials observed as failure to explode, the middle portion (under the explosive) of the flint paper was driven firmly against the anvil and had to be scraped off before proceeding to the next trial. The appearance was as if the charge had melted and refroze in a short time interval. To reproduce the appearance of these trials, the usual square of flint paper was made wet with water and then subjected to impact. This indicated that a liquid had formed in the case of TNT.

While investigating British Composition A, the escaping tendency was again observed. The heat of impact was no doubt great enough to melt the wax present, but likely not >200°C to melt the RDX. Had the melted wax penetrated the paper base, pure RDX would have remained and violent detonations should have occurred. The heat effect is real, as during an examination of ammonium picrate, a failure to explode at 150 cm. was observed and the unmelted, compressed charge was hot to touch upon rapid removal of the flint paper square from the firing chamber.

Another possible explanation in the case of both TNT and Composition A is that the impact pressure of >100 cm. drops pulverizes the flint crystals to such a fine state of subdivision that mixed with initially insensitive explosives, this mixture is more inert. The pulverized silica may form gaps between explosive particles and in turn inhibit the chain reaction.

Particle size affects results in certain cases with design 11. The effect was first noticed while investigating PETN. Three portions of a sample were examined, namely, the "as received" material, the screened fractions on 100 mesh and through 100 mesh on 200 mesh. It was observed that the "thru 100 on 200" fraction was about 1.7 times (50% explosion point) as insensitive as the other two portions. This effect was real, as 100 trials per drop-height were carried out. These data are shown in Table XIX and Figure 15. The graphs show nicely the practical shape of sensitivity curves.

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TABLE XIX
DATA FROM PETN TO SHOW PARTICLE SIZE EFFECT IN NO. 11 SENSITIVITY
DESIGN WITH A 2.5 KILOGRAM HAMMER (LARGE IMPACT MACHINE)

Drop-Height (Cm.)	As Received Portion			Fraction on 100 Mesh			Fraction through 100 mesh on 200 mesh		
	\bar{E}	\bar{N}	$\frac{\%E}{\bar{N}}$	\bar{E}	\bar{N}	$\frac{\%E}{\bar{N}}$	\bar{E}	\bar{N}	$\frac{\%E}{\bar{N}}$
6	0	100	0				0	100	0
8	1	99					0	100	0
10	7	93	7	10	90	10	0	100	0
12	35	65	35	40	60	40	0	100	0
14	84	16	84	80	20	80	4	96	4
16	96	4	96	80	20	80	1	99	1
20	98	2	98	94	6	94	32	68	32
25				96	4	96	80	20	80
30							94	6	94
35							100	0	100

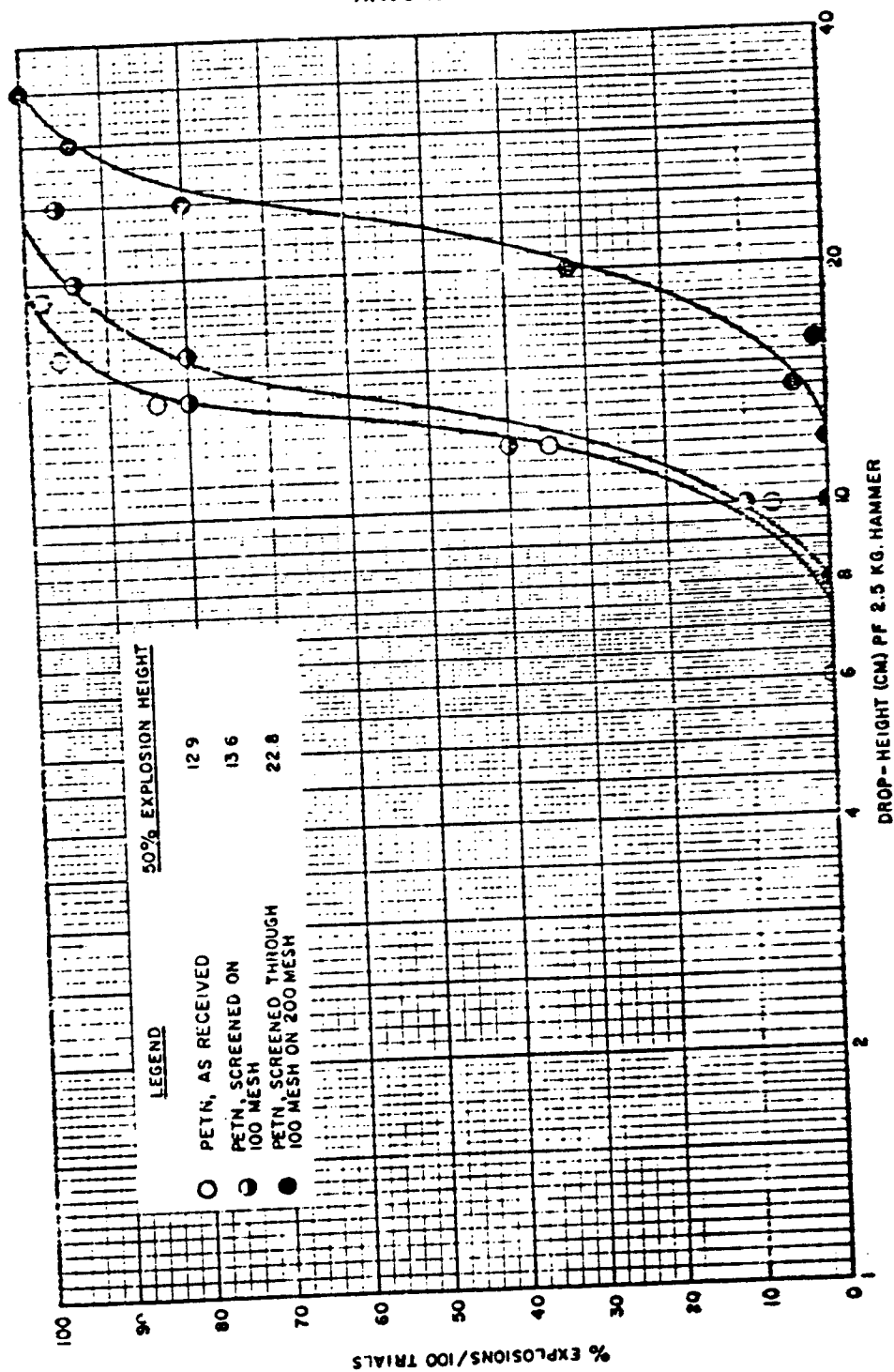


FIG. 15 SENSITIVITY OF PETN BY DESIGN NO. II

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It was thought that crystals of the less sensitive fraction were forced or packed around the flint crystals to escape much of the impact energy. Impact pressures from 8-16 cm. drops were not great enough to pulverize, to much degree, the flint crystals and friction effects are much less than with drops of 25-30 cm. Particles screened through 100 mesh are of the order 75-145 μ (110 μ average) in diameters, while the flint particles themselves average 75 μ . A comparison of particle size here would indicate that the explosive was encountering friction and that our hypothesis concerning crystal packing is incorrect; however, since PETN must be screened while water wet and be brushed or washed through the screen meshes, there is a strong tendency for sharp, irregular edges to be removed and decrease the sensitivity to frictional effects; whereas crystals of the more sensitive portions are apt to be irregular in shape and surface and in turn be more sensitive to these friction effects. Too, the 110 μ diameter particles are able to be packed into the spaces between the flint crystals, as these spaces are of the order .08 - .20 mm. (80-200 μ) in width. The packed crystals act as a cushion for crystals above and thus minimize friction effects. Crystals from the other portions are unable to pack into spaces as their diameters are >150 μ and consequently receive more frictional effects and explode with greater ease.

At a later date the less sensitive fraction was retested using flint papers of 2/0, 3/0 and 5/0 specifications. Flint particles of 3/0 specifications are of the order 58-82 μ diameters while 5/0 are from 30-60 μ in diameter. The intercrystal spaces approximate 40-80 μ for 5/0 paper. The choice of a finer grained flint paper was an attempt to eliminate the packing effect. The effect of the finer papers was compared with 20 trials at 12 cm. for each type and using the "on 200 mesh" portion of the PETN. The probability to explode was for 2/0, 3/0 and 5/0 respectively .55, .55 and .90. This was concerning as there were no explosions in 100 trials at 12 cm. in the case of the previous work with 2/0 paper. The different behavior was attributed to larger crystals being tested. The sample which exploded with a probability of .55 was the remainder of that used for the 100 trial/height study, and it was reasoned that larger crystals, i.e., the upper limit of the 75-145 μ particles, were present in the sample bottle. Since only 1-2 grams of the original 10-15 grams was remaining, it seems logical that larger, heavier crystals of 145 μ diameters would settle to the bottom of the sample bottle. The use of a finer paper eliminated to a greater degree the particle size effect, as seen in Table XX. More extensive comparison of 2/0 and 5/0 paper with PETN, as received, is shown in Table XXI and

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Figure 16. These latter data were obtained on the small impact machine. It is of interest to note that 50% explosion heights are similar in magnitude for 2/0 and 5/0 flint papers.

Recent data with colloid milled and screened PETN indicate these to be more sensitive than as received material. Figures 17-19 show the probability graph paper plots of these data from Table XXI. This most recent work tends to reverse the earlier findings and the screened PETN was seen to be the most sensitive. This leaves doubt as to the explanation of earlier phenomena. There is one other explanation which has not been mentioned. It is possible that the 1/2" striker was pitted and that the screened PETN was not receiving the same impact as the as-received sample. This is only a hypothesis, as the striker for that original work has since been refaced; however, RDX and TNT data agree with recent findings with PETN.

It is of interest to note (recent data) that as the PETN crystals become finer, the material becomes independent of the size of flint paper used; and practically identical 50% explosion heights result. The greatest differences between 2/0 and 5/0 papers are seen to occur at 10 and <10 cm. drop-heights (see Table XXI).

Plate VII shows a photomicrograph of 2/0 flint paper under a magnification of 12.5. The circular area represents about 4 mm. of surface. Notice the inter-crystal spaces into which small crystals could pack. The spaces appear as black areas at the base of the particles and vary in diameter from 1-3 mm. which correcting for magnification gives .08 - .20 mm. diameters.

Plate VIII shows a similar photomicrograph of the 5/0 flint paper. Notice that inter-crystal spaces are much reduced in magnitude.

Plate IX shows the surface of 2/0 flint paper following the impact of a 2.5 kilogram hammer falling from 12 cm. Plate X shows another 2/0 surface following an impact from a 150 cm. drop. The pulverizing of the flint is negligible in Plate IX, while in Plate X the pulverized silica could well mix with insensitive explosive during impact to, in turn, form a still less sensitive mixture.

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PLATE VII
2/0 FLINT PAPER
12.5 MAGNIFICATION



PLATE VIII
5/0 FLINT PAPER
12.5 MAGNIFICATION



PLATE IX
PULVERIZED 2/0 SILICA
FROM 12 CM. DROP
OF 2.5 KG. HAMMER



PLATE X
PULVERIZED 2/0 SILICA
FROM 150 CM. DROP
OF 2.5 KG. HAMMER

TABLE XX

COMPARATIVE DATA WITH SCREENED PETN AS TESTED BY DESIGN 11
WITH DIFFERENT FLINT PAPERS AND 2.5 KG. HAMMER

Height (Cm.)	2/0 Paper		5/0 Paper	
	Trials	%E	Trials	%E
10	20	0	20	0
12	20	0	20	15
14	20	10	20	50
16	20	35	20	75
18	20	50	20	70
20	20	80	20	100

TABLE XXI

COMPARATIVE PETN DATA BY DESIGN NO. 11 ON SMALL IMPACT MACHINE
THE %E IS THE RESULT OF 100 TRIALS (UNLESS INDICATED)

Drop Height (Cm.)	PETN, As Received				PETN, Colloid Milled				PETN, Screened thru 100 on 200			
	2 Kg. Hammer		5 Kg. Hammer		2 Kg. Hammer		5 Kg. Hammer		5 Kg. Hammer		5 Kg. Hammer	
	2/0	5/0	2/0	5/0	2/0	5/0	2/0	5/0	2/0	5/0	2/0	5/0
	Flint	Flint	Flint	Flint	Flint	Flint	Flint	Flint	Flint	Flint	Flint	Flint
2						0*			0**			0**
4					0	2*			2*		16	
6			0	0	7	4			3		77	
8		0	1	19	11	20		0	6		94	
10		4	11	45	32	31		17	65		98	
15	0	34	89	89	84	85		62	89		100	
20	50	75	98	99	96	98		97	100			
30	62	94	100	100	100	100		100				
40	87	99										
50	93	100										

(*50 Trials - ** 40 Trials)

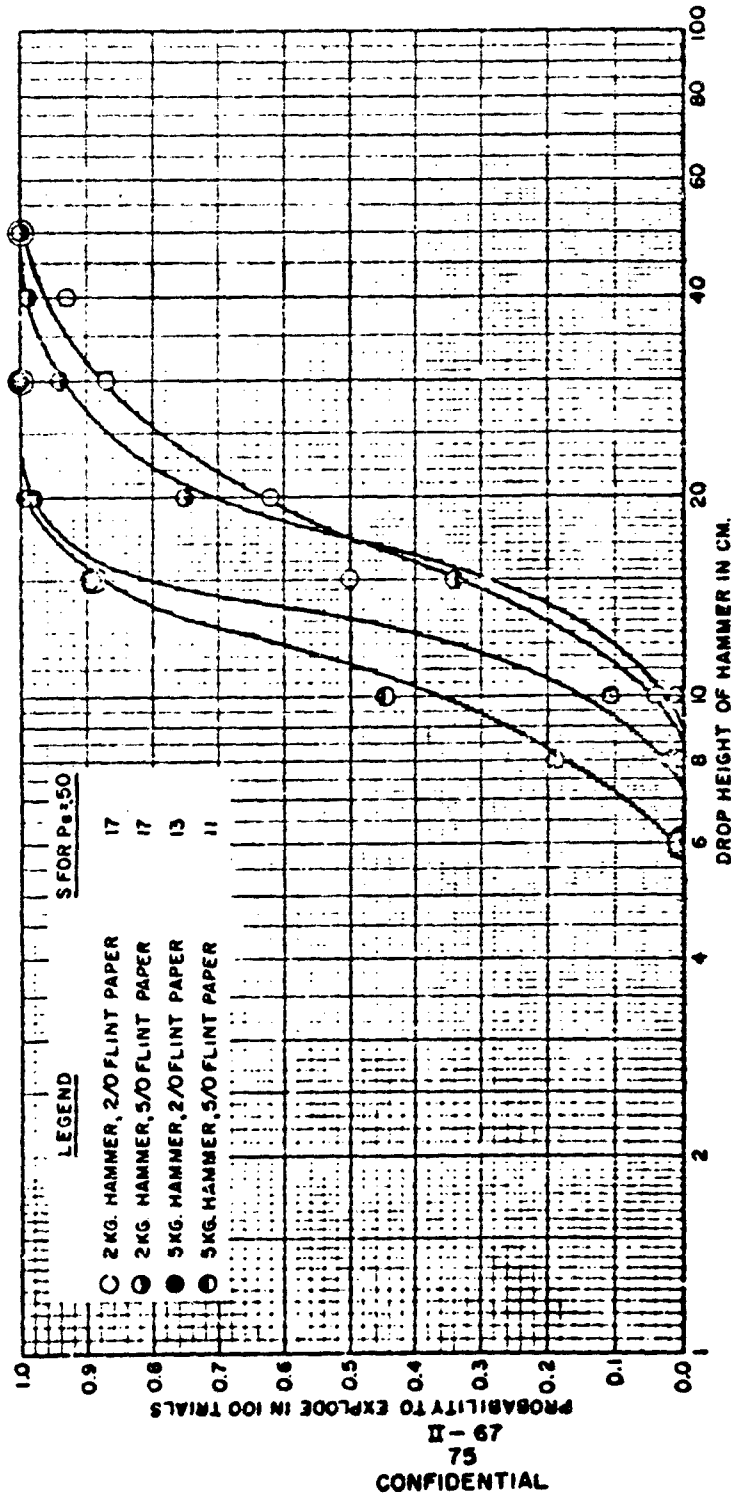


FIG. 16 BEHAVIOR OF PETN TO DIFFERENT FLINT PAPERS AND DIFFERENT
DROP-HAMMERS AS TESTED BY DESIGN NO. 11

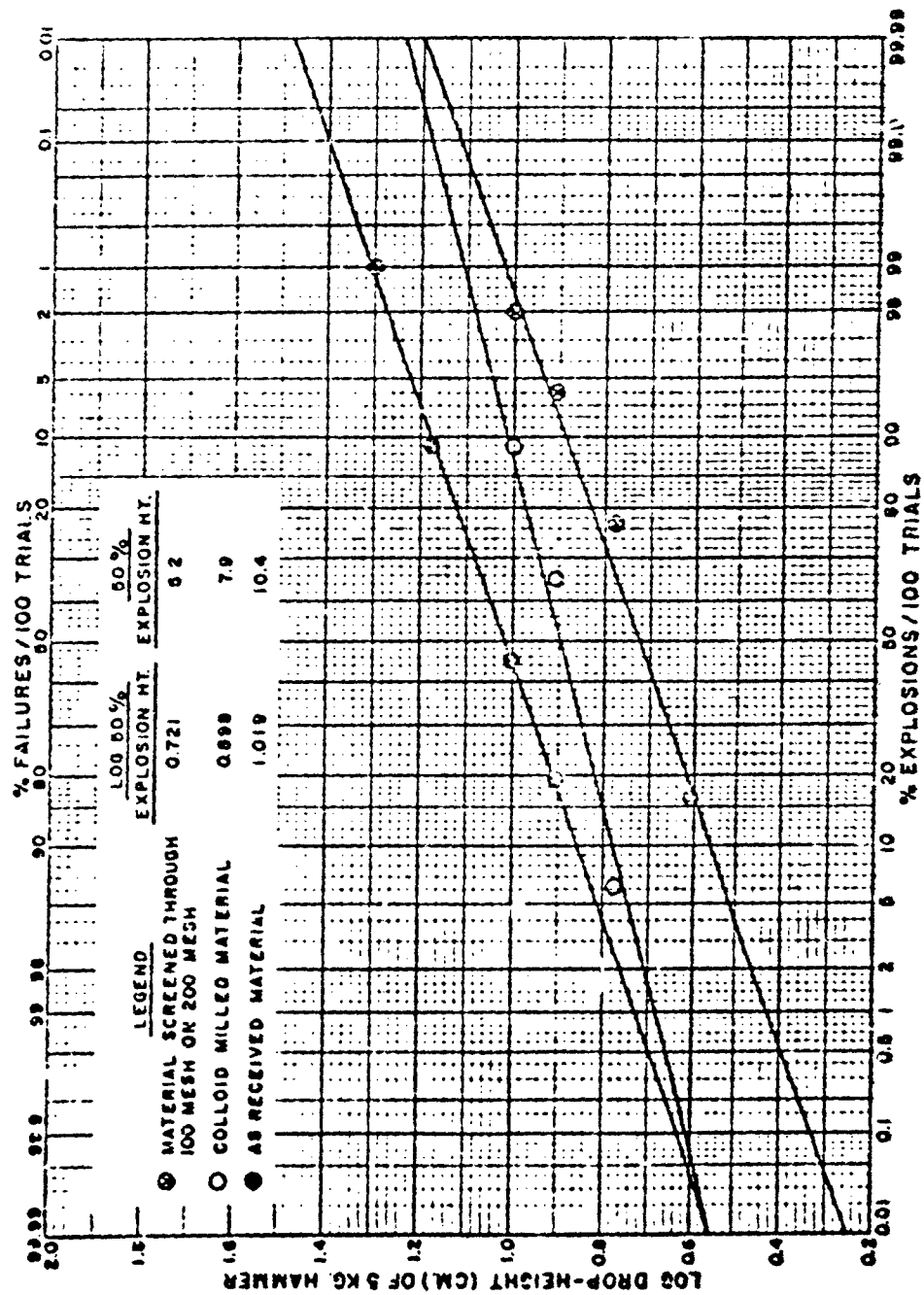


FIG. 17 COMPARATIVE PETN SENSITIVITIES AS INVESTIGATED
BY DESIGN II AND 5/O FLINT PAPER

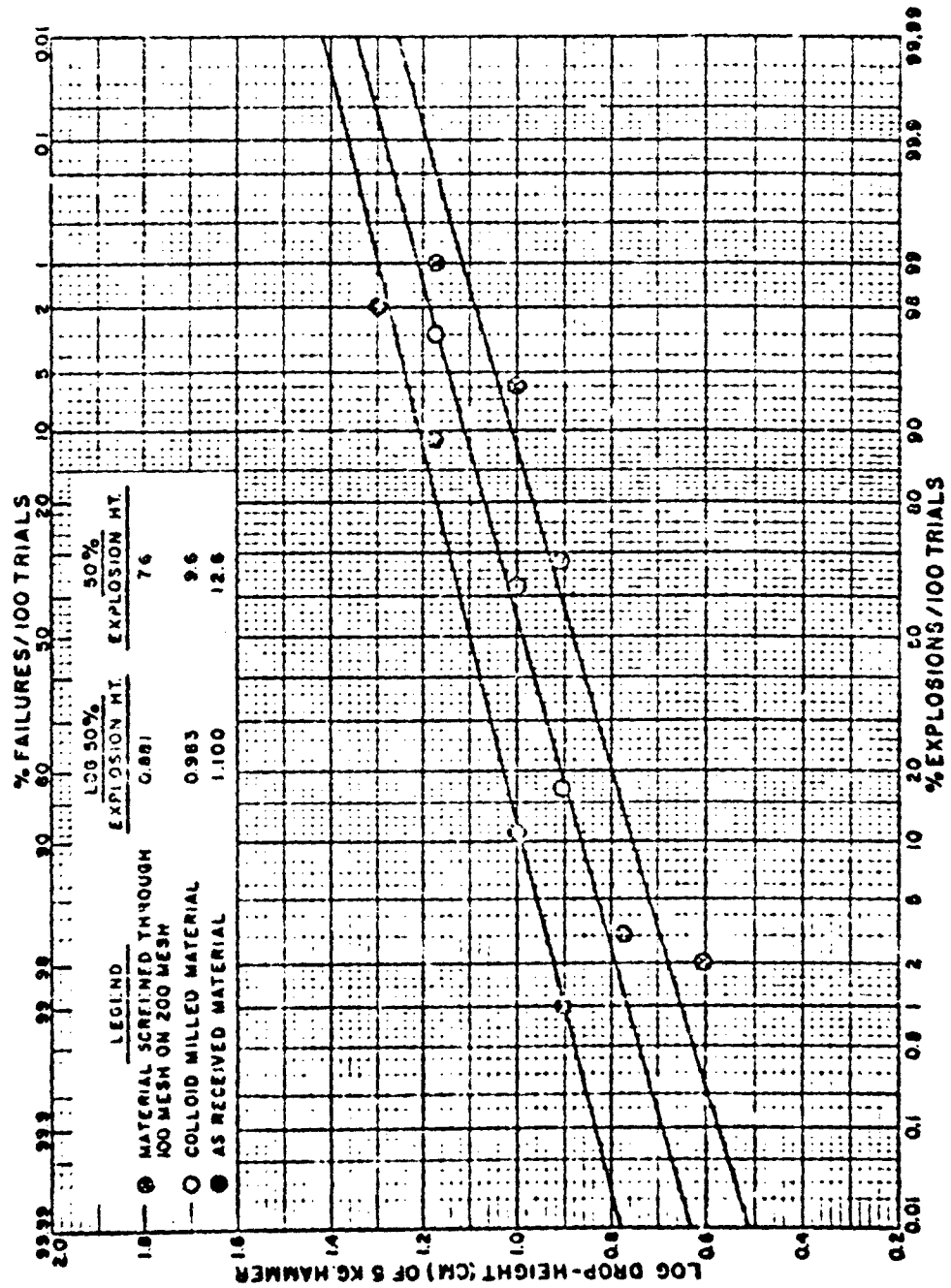


FIG. 18 COMPARATIVE PETN SENSITIVITIES AS INVESTIGATED
BY DESIGN II AND 2/0 FLINT PAPER

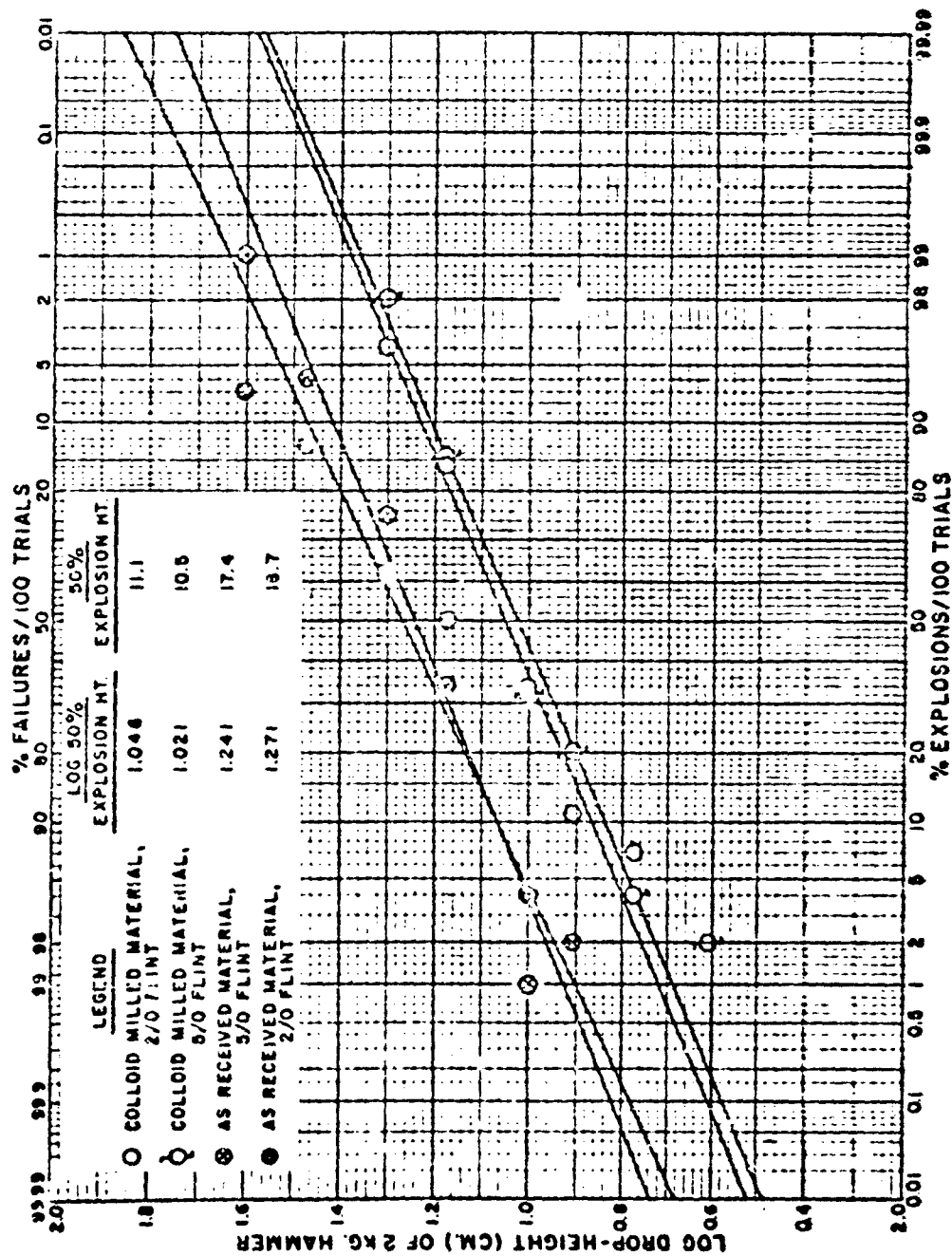


FIG. 19 COMPARATIVE SENSITIVITIES OF PETN AS STUDIED
BY DESIGN NO. II

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Screened portions of RDX were investigated by the No. 11 design as to the possibility of a packing effect similar to the earlier PETN data; however, the reverse was found to be true, as the finer particles appeared more sensitive on 2/0 paper than the as received portion. Table XXII shows these data for 50 trials per drop-height. Further comparative data with a 2.5 kilogram hammer are shown in Table XXIII.

The effect of particle size was further seen with two TNT samples. Again, the effect was seen with 2/0 flint paper. A TNT, coded R-1321, appeared more sensitive than another, coded R-1628. Microscopic examination showed a difference in particle sizes. Particles of R-1321 were in the order of 100 μ in diameter, while those of R-1628 appeared > 200 μ . The behavior seems in agreement with RDX and recent data with PETN.

Direct comparison of R-1321 and R-1628 on the same day showed the following average probability to explosion for 20 trials.

<u>Drop Height</u>	<u>75</u>	<u>100</u>	<u>125</u>
R-1321	$P_e = .60$	$P_e = .95$	$P_e = .725$
R-1628	$P_e = .425$	$P_e = .60$	$P_e = .60$

Overall comparison of the same gave the following data, indicating again a difference.

<u>Drop-Height (cm.) of 2.5 Kg. Hammer</u>	<u>R-1321</u>		<u>R-1628</u>	
	<u>Trials</u>	<u>Ave. P_e</u>	<u>Trials</u>	<u>Ave. P_e</u>
50	60	.133	100	.18
55	40	.175		
60	40	.555	100	.255
65	40	.65		
70	40	.75	100	.37
75	80	.788	20	.425
80	40	.90	100	.46
90			100	.52
100	80	.975	120	.683
125	20	.725	120	.575
150			100	.595

TABLE XXII
SMALL MACHINE DATA WITH SCREENED RDX BY DESIGN 11 AND 2.0 KILOGRAM
DROP HAMMER

RDX Drop Height (Cm.)	As Received			Purified			As Received on 100 mesh			As Received on 200 mesh			As Received Through 200 mesh		
	E		N	E		N	E		N	E		N	E		N
	P _c			P _c			P _c			P _c					
30	39	11	.78	34	16	.68	38	12	.76	45	5	.90	42	8	.84
50	47	3	.94	49	1	.98	50	0	1.00	47	3	.94	50	0	1.00

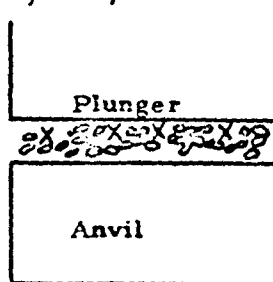
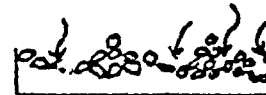
TABLE XXIII
LARGE IMPACT MACHINE DATA WITH SCREENED RDX BY DESIGN 11 AND
2.5 KILOGRAM DROP-HAMMER

RDX Drop Height (Cm.)	As Received			On 100 mesh			Thru 100 mesh on 200 mesh			Thru 200 Mesh					
	E	D	N	Av.		E	D	N	Av.		E	D	N	Av.	
				P _c	N				P _c	N				P _c	N
10	2	1	17	.125	0	0	0	20	0	0	0	0	20	0	0
15	4	0	16	.20	3	1	16	.175	3	1	16	.175	7	1	12
20	11	1	8	.575	6	0	14	.30	8	0	12	.40	28	1	11
25	16	0	4	.80	12	0	8	.60	13	0	7	.65	13	0	7
30	19	0	1	.95	14	0	6	.70	18	0	2	.90	18	0	2
35	20	0	0	1.00	18	0	2	.90	20	0	0	1.00	20	0	2

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In the case of TNT, the sensitivity to frictional effects is less as the crystals are easily compressed and have soft, easily fractured edges. It seems possible that this material may be compressed past flint crystals and escape friction. A confinement effect may also be present. Smaller crystals of R-1321 are able to a greater degree to fit into depressions or spaces between the flint crystals and are confined to a greater degree than larger particles ($>200\mu$) of R-1628. These entrapped crystals represent more confinement during impact, and in turn give more explosions and of more violent intensity than larger crystals which lack the initial confinement from entrapment. In the case of PETN, the material is friction sensitive and less dependent upon confinement. Too, the drop-heights are much different for PETN and TNT to cause a tremendous difference in confinement during impact.

Surface of flint paper (cross section)
(arrows indicate spaces for
entrapment of crystals)




X = entrapped crystal

Confinement During Impact

These are under more confinement than an explosive crystal resting atop the flint crystal, especially if drop-height is >20 cm. With PETN, very little, if any, crushing of the flint crystals occurs and the phenomena become tribochemical in nature at drop-heights of 8-16 cm. for larger crystals.

Several explosives were tested in the conventional procedure by design 11, and these results are shown in Table XXIV and Figure 20-25, with significant data likewise present.

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Drop-Height (cm) of 2.5 kg Hammer	Nitromannite				PETN				RDX				E
	E	D	N	Ave. %E	E	D	N	Ave. %E	E	D	N	Ave. %E	
2	0	0	20	0									
4	2	0	38	5	-	-	-	-					
6	18	0	22	45	0	0	100	0					-
8	25	0	35	41.7	1	0	99	1	-	-	-	-	0
10	32	0	8	80	7	0	93	7	7	1	32	18.8	2
12	38	0	2	95	35	0	65	35	-	-	-	-	-
14	19	0	1	95	84	0	16	84	-	-	-	-	-
15	-	-	-	-	-	-	-	-	20	0	100	16.7	6
16	20	0	0	100	96	0	4	96	-	-	-	-	-
18	-	-	-	-	-	-	-	-	25	0	35	41.7	-
20					98	0	2	98	154	1	185	45.4	14
25					-	-	-	-	83	0	57	59.2	17
30									115	0	25	82.2	19
35									78	0	2	97.5	19
40									40	0	0	100	-
45									20	0	0	100	
50									-	-	-	-	
60													
70													
75													
80													

	NENO				Tetryl				Pentolite				EDNA			
Ave. %E	E	D	N	Ave. %E	E	D	N	Ave. %E	E	D	N	Ave. %E	E	D	N	Ave. %E
	-	-	-	-												
-	0	0	20	0					-	-	-	-				
18.8	2	4	13	20					0	1	19	2.5				
-	-	-	-	-					-	-	-	-				
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
16.7	6	5	9	42.5	0	0	20	0	0	4	16	10	1	0	39	2.5
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
41.7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
45.4	14	2	4	75	-	-	-	-	0	5	15	12.5	7	1	32	18.8
59.2	17	1	2	87.5	-	-	-	-	4	7	9	37.5	15	4	41	28.3
82.2	19	0	1	95	55	9	76	42.9	11	4	5	65	68	2	90	43.1
97.5	19	0	1	95	38	0	22	63.3	14	5	1	82.5	69	3	48	58.7
100	-	-	-	-	52	0	8	86.7	19	1	0	97.5	63	2	35	64
100					40	0	0	100	-	-	-	-	40	0	20	66.7
-					20	0	0	100	20	0	0	100	84	0	16	84
					-	-	-	-	-	-	-	-	54	0	6	90
													37	0	3	92.5
													-	-	-	-

TABLE XXIV

SUMMARY OF DESIGN NO. 11 SENSITIVITY DATA

2

IN	RDX				NENO				Tetryl				Pentolite			
	Ave. N %E	E	D	N %E	Ave. N %E	E	D	N %E	Ave. N %E	E	D	N %E	Ave. N %E	E	D	N %E
-	-															
00	0					-	-	-	-							
99	1	-	-	-	-	0	0	20	0					-	-	-
93	7	7	1	32	18.8	2	4	13	20					0	1	19
55	35	-	-	-	-	-	-	-	-					-	-	-
16	84	-	-	-	-	-	-	-	-					-	-	-
-	-	20	0	100	16.7	6	5	9	42.5	0	0	20	0	0	4	16
4	96	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	25	0	35	41.7	-	-	-	-	-	-	-	-	-	-	-
2	98	154	1	185	45.4	14	2	4	75	-	-	-	-	0	5	15
-	-	85	0	57	59.2	17	1	2	87.5	-	-	-	-	4	7	9
		115	0	25	82.2	19	0	1	95	55	9	76	42.9	11	4	5
		78	0	2	97.5	19	0	1	95	38	0	22	63.3	14	5	1
		40	0	0	100	-	-	-	-	52	0	8	86.7	19	1	0
		20	0	0	100					40	0	0	100	-	-	-
		-	-	-	-					20	0	0	100	20	0	0
										-	-	-	-	-	-	-

TABLE XXIV

SUMMARY OF DESIGN NO. 11 SENSITIVITY DATA

Pentolite				EDNA				Ammonium Perchlorate				Fivonite			
<u>E</u>	<u>D</u>	<u>N</u>	<u>Ave.</u> <u>%E</u>	<u>E</u>	<u>D</u>	<u>N</u>	<u>Ave.</u> <u>%E</u>	<u>E</u>	<u>D</u>	<u>N</u>	<u>Ave.</u> <u>%E</u>	<u>E</u>	<u>D</u>	<u>N</u>	<u>Ave.</u> <u>%E</u>
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0	1	19	2.5	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0	4	16	10	1	0	39	2.5	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0	5	15	12.5	7	1	32	18.8	0	1	19	2.5	7	2	11	40
4	7	9	37.5	15	4	41	28.3	-	-	-	-	11	2	7	60
11	4	5	65	68	2	90	43.1	7	3	10	42.5	17	3	0	92.5
14	5	1	82.5	69	3	48	58.7	-	-	-	-	-	-	-	-
19	1	0	97.5	63	2	35	64	11	2	7	60	18	2	0	95
-	-	-	-	40	0	20	66.7	-	-	-	-	-	-	-	-
20	0	0	100	84	0	16	84	12	2	6	65	19	1	0	97.5
-	-	-	-	54	0	6	90	14	1	5	72.5	-	-	-	-
-	-	-	-	37	0	3	92.5	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	17	0	3	85	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

2

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Drop-Height (cm) of 2.5 kg Hammer	Emmet				Stonite				Picric Acid				Composition B				Composition A				E
	E	D	N	Ave. SE	E	D	N	Ave. SE	E	D	N	Ave. SE	E	D	N	Ave. SE	E	D	N	Ave. SE	
2																					
4																					
6																					
8	-	-	-	-					-	-	-	-									
10	0	1	19	2.5					0	0	20	0									
12	-	-	-	-					-	-	-	-									
14	-	-	-	-					-	-	-	-									
15	0	2	18	5					-	-	-	-									
16	-	-	-	-					-	-	-	-									
18	-	-	-	-					-	-	-	-									
20	2	3	15	17.5					1	0	19	5	0	1	19	2.5					
25	10	1	9	52.5					-	-	-	-	-	-	-	-					
30	18	0	2	90	-	-	-	-	2	3	15	17.5	0	5	15	12.5					
35	18	1	1	92.5	0	1	19	2.5	-	-	-	-	-	-	-	-					
40	19	1	0	97.5	0	8	12	20	6	1	13	32.5	2	5	10	30					
45	-	-	-	-	5	5	10	37.5	-	-	-	-	-	-	-	-					
50	19	1	0	97.5	11	7	2	72.5	5	1	14	27.5	2	3	15	17.5					6
60	-	-	-	-	17	3	0	92.5	5	0	15	25	12	14	14	47.5					15
70					-	-	-	-	3	0	17	15	9	6	23	32.5	-	-	-	-	24
75					20	0	0	100	-	-	-	-	-	-	-	-	26	1	33	44.2	5
80					-	-	-	-	8	0	12	40	12	4	4	70	-	-	-	-	36
90									12	0	8	60	12	3	4	70	-	-	-	-	42
100									18	0	2	50	3	9	2	67.5	6	6	8	45	72
110									20	0	0	100	13	6	1	60	-	-	-	-	-
120									-	-	-	-	15	4	1	85	-	-	-	-	-
125													-	-	-	-	3	4	13	25	56
130													16	3	1	87.5	-	-	-	-	-
140													17	3	0	92.5	-	-	-	-	-
150													14	2	4	75	6	4	10	40	52
175													-	-	-	-	-	-	-	-	-
200																	1	6	13	20	
225																	-	-	-	-	
250																					
275																					
300																					

	Composition B				Composition A				TNT				Ammonium Picrate				Potassium Perchlorate				Drop-Height (cm) of 2.5 kg Hammer
	E	D	N	Ave. SE	E	D	N	Ave. SE	E	D	N	Ave. SE	E	D	N	Ave. SE	E	D	N	Ave. SE	
																					2
																					4
																					6
																					8
3																					10
																					12
																					14
																					16
																					18
																					20
5	3	1	19	2.5									0	0	20	0					25
																					30
17.5	0	5	15	12.5																	35
																					40
32.5	2	5	10	30																	45
													2	0	38	5					50
27.5	2	5	15	17.5					6	24	70	18									60
25	12	14	14	47.5					15	21	64	25.5									70
15	9	6	23	32.5					24	26	50	37	11	0	29	27.5	0	0	20	0	75
					26	1	33	44.2	5	7	8	42.5									80
40	12	4	4	70					36	20	44	46									90
60	12	4	4	70					42	20	38	52	20	5	17	58.8	6	0	14	30	100
50	3	9	2	67.5	6	6	8	45	72	22	26	69.1									110
100	13	6	1	60																	120
	15	4	1	85									31	0	9	77.5	4	0	16	20	125
					3	4	13	25	56	22	42	56									130
	16	5	1	87.5																	140
	17	5	0	92.5									35	2	3	90	6	0	14	30	150
	14	2	4	75	6	4	10	40	52	15	33	59.5	39	0	1	97.5					175
													19	1	0	97.5	8	0	12	40	200
					1	6	13	20									3	1	16	17.5	225
																	14	0	6	70	250
																	33	0	7	82.5	275
																	19	0	5	75	300

TABLE XXIV, Cont'd.
SUMMARY OF DESIGN NO. 11 SENSITIVITY DATA

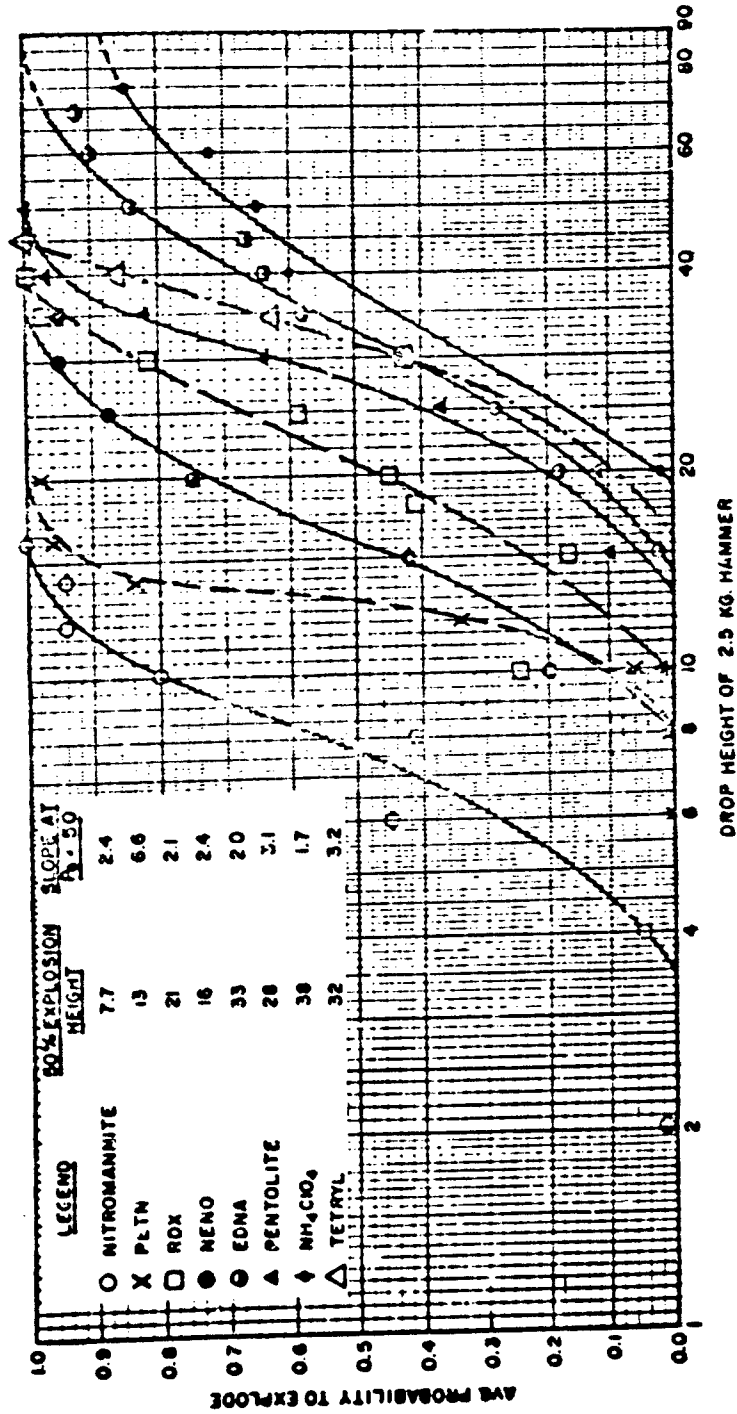


FIG. 20 PRACTICAL COMPARATIVE SENSITIVITIES BY DESIGN NO.11

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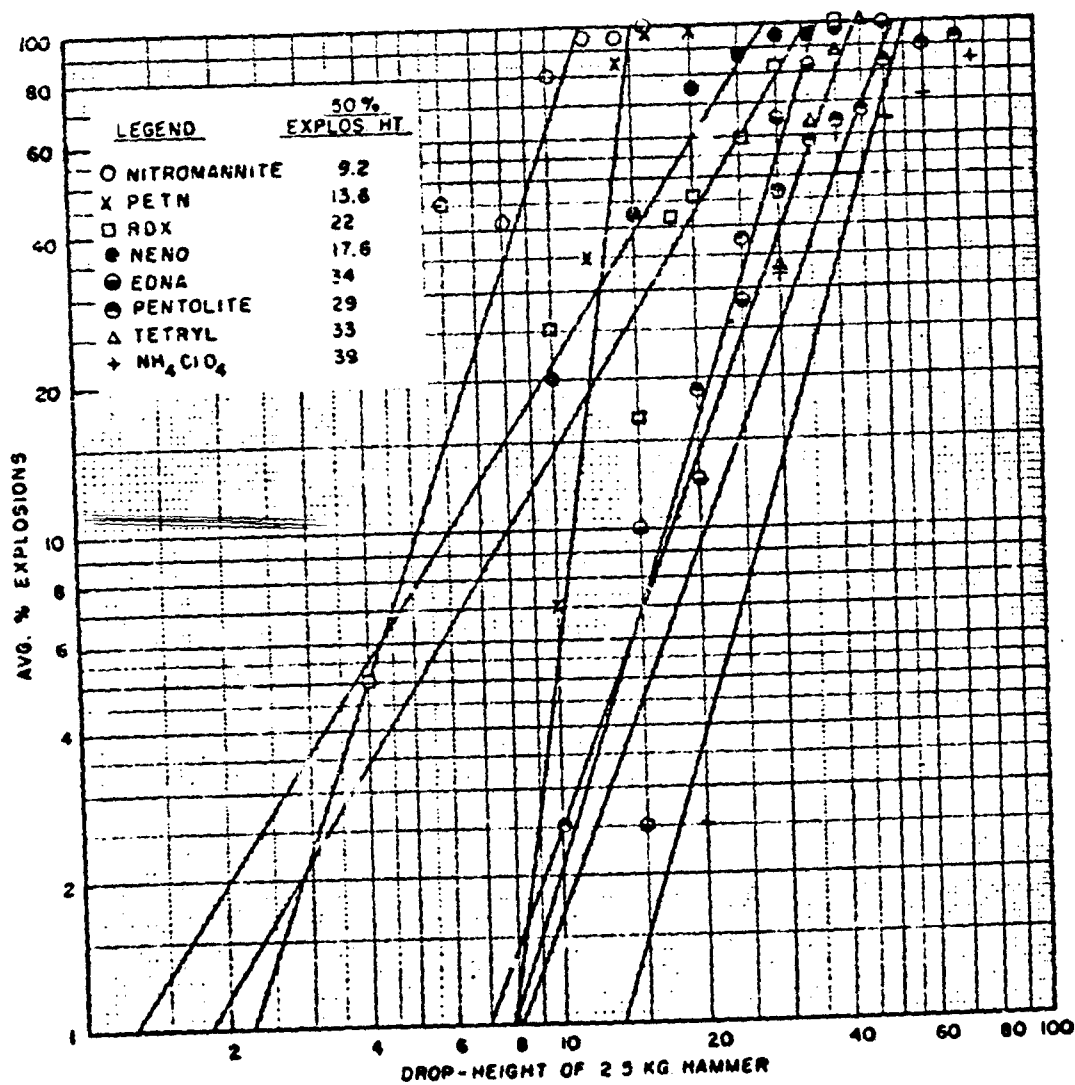


FIG. 21 THEORETICAL SENSITIVITIES BY DESIGN NO. 11

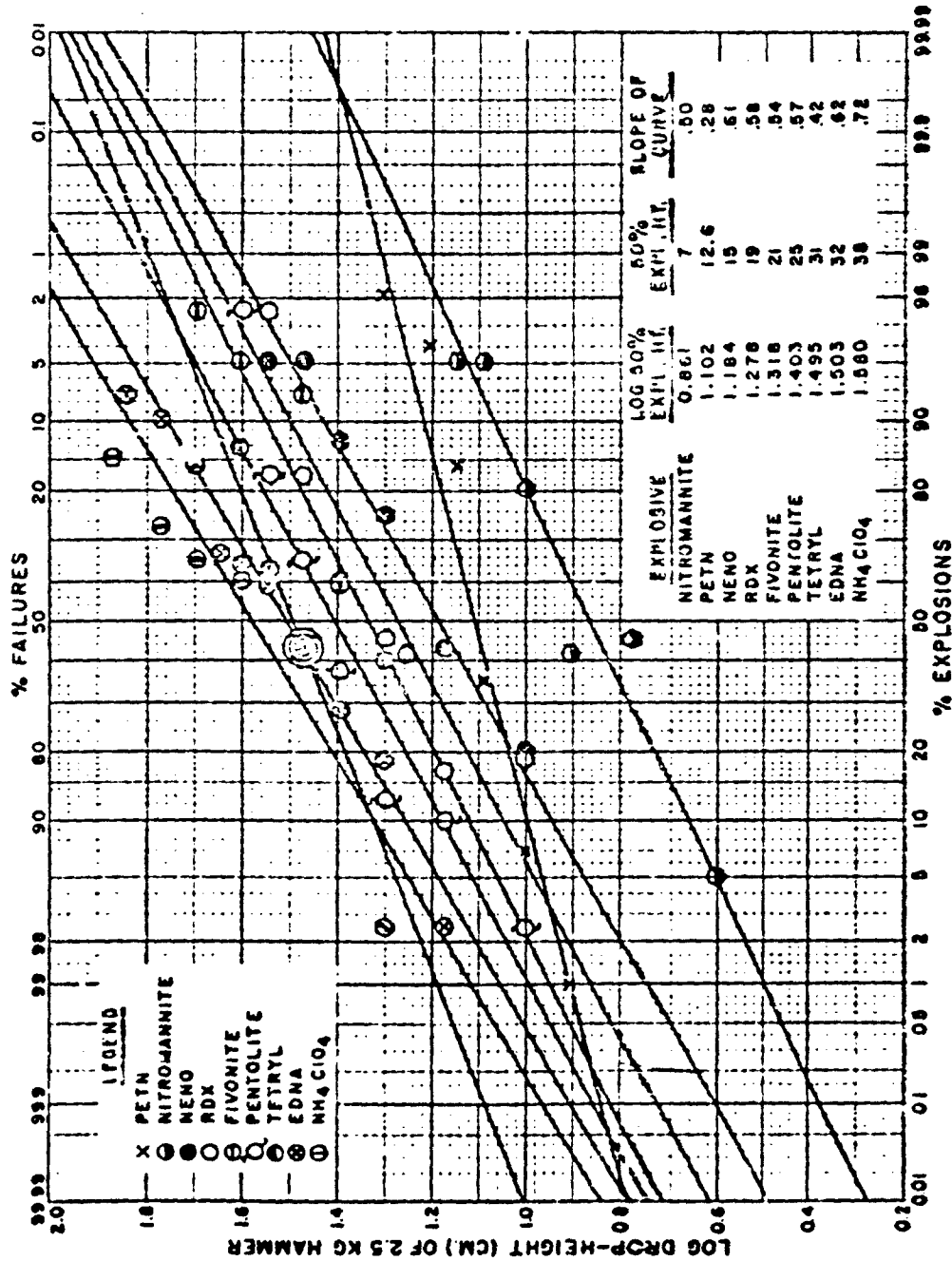


FIG.22 COMPARATIVE SENSITIVITIES BY DESIGN NO.11

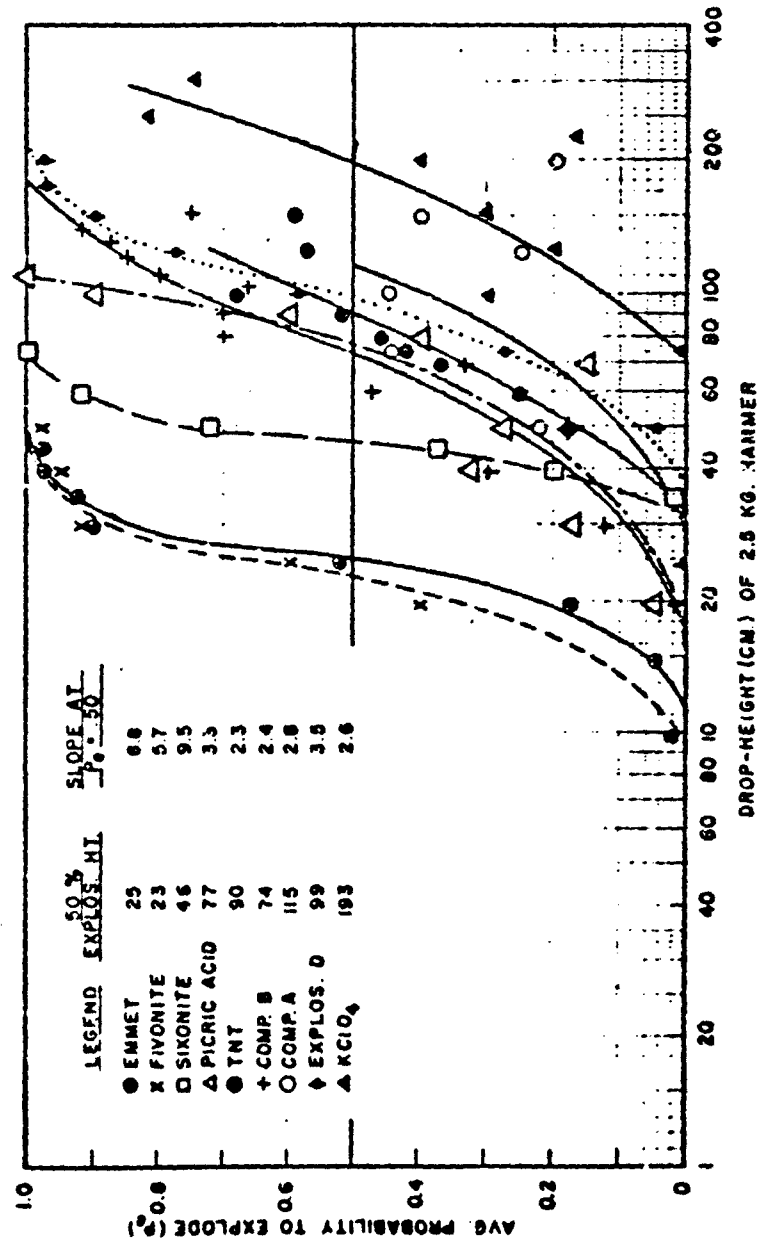


FIG. 23 COMPARATIVE SENSITIVITIES BY DESIGN NO. II

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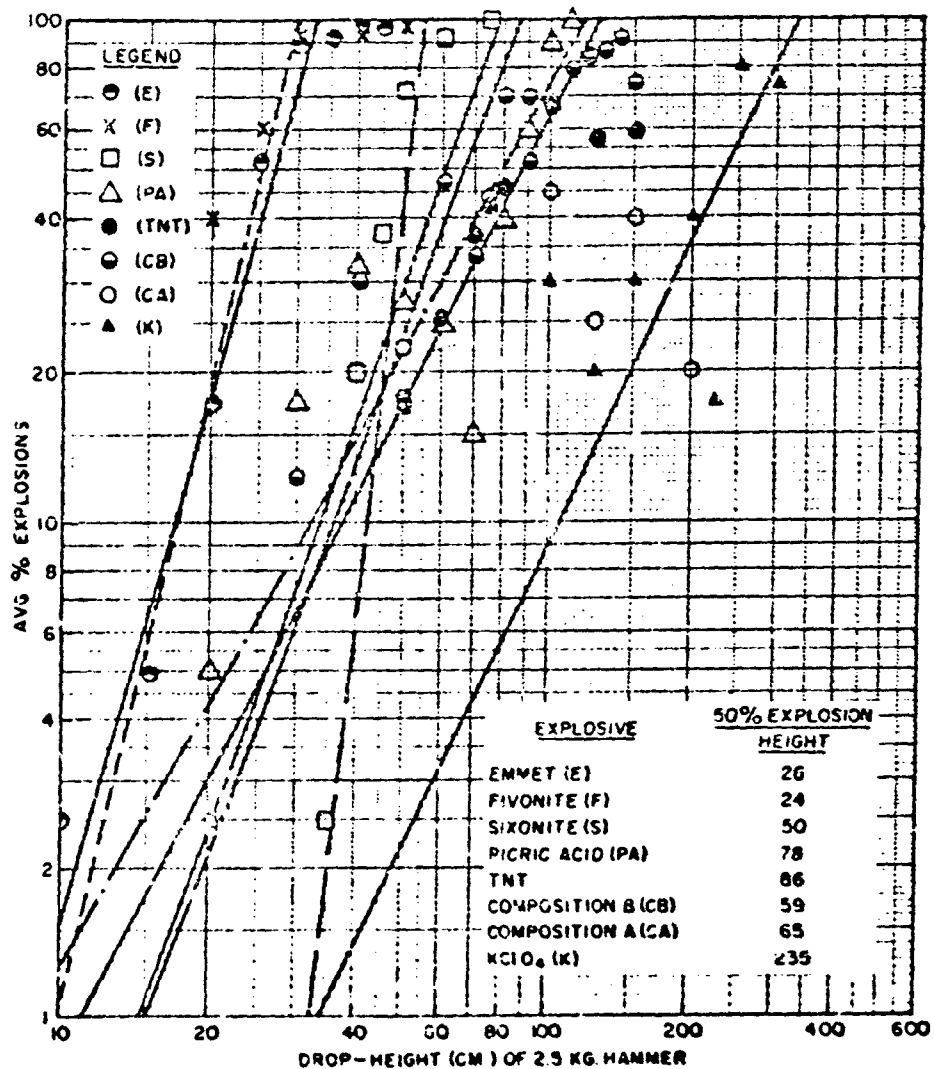


FIG. 24 THEORETICAL SENSITIVITIES BY DESIGN NO. 11

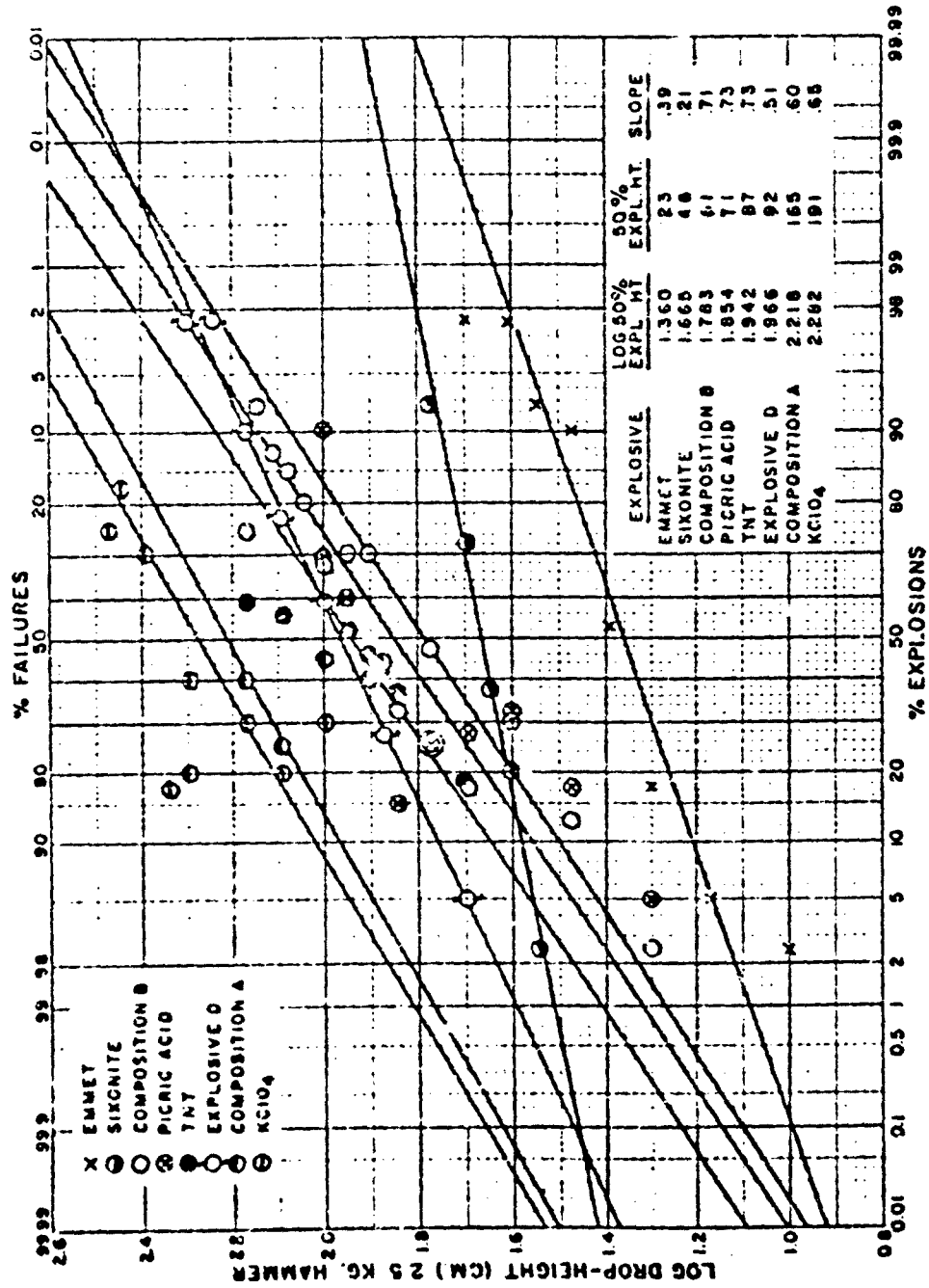


FIG. 25 COMPARATIVE SENSITIVITIES BY DESIGN NO. II

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In conclusion it may be said that, for explosives in the higher and intermediate range of sensitivity, design 11 is satisfactory. The cushioning effect of the paper itself enters the picture with such substances as mercury fulminate, lead styphnate and lead azide. One may expect explosions in the region of 1-8 cm.; but until the cushioning factor is reduced (>10 cm. drops) explosions will be few. Unfortunately this design is not satisfactory for certain explosives of low sensitivity as at drops >100 cm. the identification of explosion becomes difficult and the 100% explosion mark is not reached. For materials of soft, waxy consistency, not much better than 50-75% explosions are obtained as the drop-height is increased. To overcome this difficulty, a striker of 1 1/4" diameter was substituted for the 1/2" striker of design No. 11 and the development of design 12 was undertaken.

The No. 12 Design

As mentioned above, this method was a revised No. 11. The large striker was found to be satisfactory and 100% explosion drop-heights were obtained. This pointed in general direction that once again, the escape of the sample was occurring in the No. 11 case. The No. 12 design also involved the use of 5/0 flint paper in hopes of eliminating any particle size effect, as was the case with a flint paper of 00 specification.

A previous report (March, 1944) summarized most of the important comparative data for Design 12; however, some additional data are presented here. *

Table XXV shows that the particle size difficulty has been minimized for PETN, when tested by Design 12.

*The report referred to is not available although it is believed that the material is included in report 3 which is the next section.

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TABLE XXV
COMPARATIVE DATA FOR PETN BY DESIGN 12

Drop-Height 2.5 Kg. Hammer	As Received Mat'l		Screened Material Through 100 mesh on 200 mesh	
	<u>Trials</u>	<u>P_e</u>	<u>Trials</u>	<u>P_e</u>
10	20	.35	40	.575
12	20	.60	40	.60
14	20	.70	40	.95

In September, 1943, several polymorphic forms of TNT from Cornell University were investigated by Design 12. Several of these samples appeared more sensitive than regular TNT at intermediate (40-75 cm.) drop-heights. The more sensitive material was very light and fluffy in texture and the amount used per trial amounted to about 1/3 that of regular TNT. It was learned that the same lower order of sensitivity could be obtained with regular TNT if a 5-8 mg. charge be used instead of the usual 20-25 mg. charge. Also, if low density (0.25) TNT were tested, the same lower order of sensitivity was present. It was interesting to note that the difference in sensitivity disappears at drop-heights >75 cm. and also if the same weight of sample be used for comparative testing. Table XXVI presents in summary form the data discussed above.

Designs 11 and 12 involved the use of a new idea in qualitative interpretation. To approach quantitatively the fact that TNT may char or feebly "explode" at a drop-height at which PETN detonates furiously, it was decided to evaluate such weak decompositions as a D or doubtful explosion. In conventional procedure, it amounted to 1/2 explosion. For example, in a series of 20 trials if 10 showed E or explosion, 7 N or failures and 3 D or doubtful explosions, the %E + D with D = E would be 65 while %E with D = N would be 50. The average % E would be 65 + 50 divided by 2 = 57.5. The above procedure gives a quantitative approach to the question of degree or intensity of explosion, which is most important in sensitivity studies. Explosions are qualitatively separated into various types according to the degree of explosion with

TABLE XXVI
COMPARISON OF REGULAR AND "SENSITIVE" TNT BY DESIGN 12

Drop-Height (cm.) of 2.5 Kg. Hammer	Cornell				Cornell				TNT of 0.25			
	"Sensitive"		"Sensitive"		TNT		Regular TNT		Density		8-10 mg/Trial	
	Trials	Ave.	Trials	Ave.	Trials	Ave.	Trials	Ave.	Trials	Ave.	Trials	Ave.
30	20	0	20	.20	20	.075	20	.15	20	.212	20	.30
40	20	.20	20	.375	20	.325	20	.30	20	.45	20	.725
50	20	.275	60	.612	20	.325	20	.475	20	.80	20	.80
75	20	.55	20	.70	20	.925	20	.925	20		20	
100	20	.80	20	.925	20		20		20		20	

Trinitrotoluene was further studied with the effect of particle size in mind. Micro milled and screened portions were compared with regular and no decided difference was seen. Table XXVII shows these data.

TABLE XXVII
COMPARATIVE TNT DATA BY DESIGN NO. 12

Drop Height (cm.)	As Received (22 mg.)		Micro Milled (26 mg.)		Screened thru 100 on 200 (21 mg.)	
	Trials	Ave. P	Trials	Ave. P	Trials	Ave. P
40	20	.175	20	.05	20	.15
50	20	.125	20	.40	20	.475
75	20	.45	20	.825	20	.425
100	20	.75	20		20	.825
50					20	.05*

* 2 scoops (42-45 mg.)

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sound as the main criterion. With certain aluminized explosives, doubtful explosions are also classified as to those accompanied with or without visible sparks or flame. Such factors as visible flame (f), loudness (l), completeness of detonation (c), nearly complete (č), and partial or low order explosibility (p) are kept in mind in symbolizing E, E_p, E_l, E_f, E_{pf}, E_{lf}, E_c, E_č, E_{cf}, E_{čf}, D, D_s, and D_f.

While the qualitative classification does not affect the value of %E or synonymous P_e, it does give information that should be considered. For instance, during a rather extensive investigation of various Torpex samples following an explosion at Yorktown, Va., it was found that a certain RDX-aluminum mixture exploded with the same intensity of explosion at the same drop-heights as mercury fulminate. Although the frequency of explosion was less than the fulminate, it was important to know that once an explosion did occur, it was most violent.

One of the disadvantages of the No. 12 design was found to be the tendency of certain oxidizing agents to react with the paper base of the flint paper. This was first noticed while investigating ammonium nitrate. A further study with this particular substance showed that appreciable reaction is experienced with certain types of non-abrasive paper, Table XXVIII. The procedure of loading the explosive was identical with Design 12, except that these various types of paper were substituted for the 5/0 flint paper.

Designs 12a, 12b and 13

Following the extensive program of sensitivity study from August through October, 1943, attention was directed to the development of a design suitable for testing liquid explosives. Development in late 1943 and early 1944 saw the use of designs 12a, 12b and 13.

Method 12b was simply No. 12 without the 5/0 flint paper. A drop of liquid from a common medicine dropper was placed in the center of the usual ketos anvil, the 1 1/4" diameter striker placed atop the charge and the weight dropped from desired heights. Method 12a employed a 1/2" square of No. 615 filter paper to absorb the liquid before impact. The striker and anvil for 12a were identical to those of 12 and 12b.

TABLE XXVIII
AMMONIUM NITRATE BEHAVIOR WITH VARIED PAPERS FOR NO. 12 DESIGN

Drop-Height (cm.) of 2.5 Kg. Hammer	5/0 Flint Paper		No. 615 Filter Paper		Type I Drawing Paper		Type II 20 lb Bond		Type III Wrapping Paper	
	<u>Trials</u>	<u>P_e</u>	<u>Trials</u>	<u>P_e</u>	<u>Trials</u>	<u>P_e</u>	<u>Trials</u>	<u>P_e</u>	<u>Trials</u>	<u>P_e</u>
100	20	7.5							40	.438
200	40	.30	40	.20	40	.20	40	.025	40	.70
250	40	.425	40	.25	40	.25	40	.025		
300	40	.675	40	.725	40	.40	40	0	40	.975

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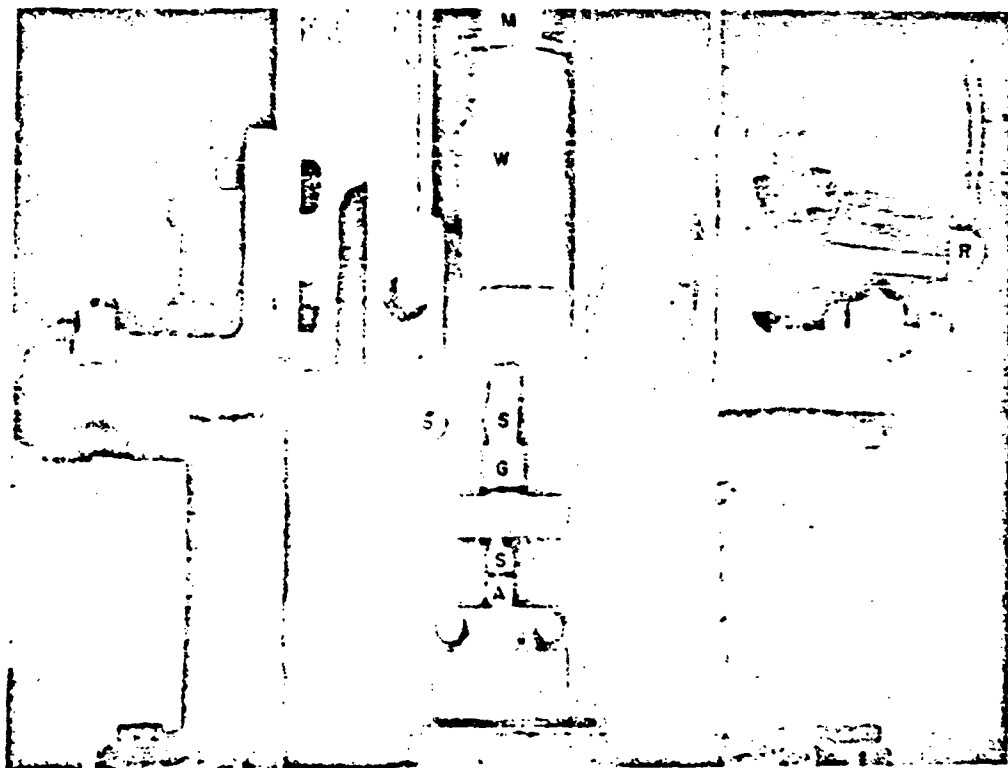
Design 13 was developed with the idea of hitting the liquid explosive semi-directly and eliminating to a greater degree the squeezing of the material from between the striker and anvil surfaces. A small wooden applicator (.075" diameter and 3 1/4" long) or "toothpick" was inserted through a 1/4" diameter hole at the top of the striker and placed across the outer guide ring to elevate the striker about 7 mm. above the charge of explosive. Plate XI illustrates design 13, while Plate VI shows 12, 12a or 12b in position to receive impact.

The wooden toothpick was elastic and naturally required some energy to be stretched so that the striker made contact with the explosive. With sensitive solid explosives the drop-heights are greater for design 13 than for 12b. Liquids, on the other hand, show greater probability to explode at lower drop-heights with design 13. The squeezing tendency present in 12a or 12b is avoided with No. 13 and liquids are able to receive more direct impact at a localized or concentrated point of application. Thin layers of poor propagating material are present in the procedure of 12b which undoubtedly require greater impact energies. Table XXIX shows comparative data for designs 12b and 13 for a sensitive liquid and solid explosive.

TABLE XXIX
COMPARATIVE DATA WITH SENSITIVE SUBSTANCES FOR DESIGNS
12b AND 13

Drop Height 2.5 Kg. Hammer	Lead Styphnate				Nitroglycerin			
	Design 12b		Design 13		Design 12b		Design 13	
	<u>Trials</u>	<u>P_{ec}</u>	<u>Trials</u>	<u>P_{ec}</u>	<u>Trials</u>	<u>P_{ec}</u>	<u>Trials</u>	<u>P_{ec}</u>
6	20	.05	10	0	10	0	20	.15
8	20	.55	20	0	20	0	20	.80
10	20	.75	20	.20	20	.05	20	.85
12					10	.50	20	.75
15	20	1.00	20	.85			10	.80
20	20	.95	20	1.00				

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- A • ANVIL
- G • INNER GUIDE RING
- S • ELEVATED STRIKER
- P • "TOOTHPICK" TO ELEVATE THE STRIKER
- W • 2.5 KILGGRAM DROP-HAMMER
- M • ELECTROMAGNET TO HOLD AND RELEASE THE HAMMER
- R • SLIDE-PLATFORM TO RECEIVE HAMMER ON REBOUNDS

PLATE XI
DESIGN NO. 13

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It is seen from Table XXIX that as the drop-height becomes >10 cm., the probabilities of explosion become the same for both designs. For explosives of intermediate and high insensitivity, the energy lost in stretching the wooden pin becomes negligible.

Design 13 was employed during the study of numerous liquid explosive mixtures. These data are summarized in Table XXX and XXXII. Graphical treatment of these data is seen in Figure 26. Solid explosives tested by design 13 are summarized in Tables XXXI and XXXIII and Figures 27-29.

Plate XII illustrates the general damage to 1 1/4" strikers by powerful explosions of 1-drop (40-50 mg.) of nitroglycerin. These are the most violent explosions encountered in sensitivity studies. The pitted anvil (A) of Plate XII is due to the action of mercury fulminate exploding. Strikers and anvils are usable for about 5-10 trials with this substance, and then require refacing.

Figure 30 shows the linear relationship between the logarithm of the 50% explosion height and the percentage of desensitizer in a liquid explosive mixture of sensitive and insensitive substances. Note the amount of desensitizer required for the nitroglycerin to make it safe, yet explosive. This latter value in % desensitizer is in the order 35-50%.

Table XXXIV and Figure 31 show data for now discontinued design 12b. This design has been discontinued with solid explosives because of a disturbing reason. It was found that the 50% explosion height for PETN was about 70 cm., provided the striker was merely rested atop the usual heaped charge. However, if the charge were flattened by pressing firmly on the striker and at the same time spinning the striker to give a thin layer of PETN of 1 1/4" diameter, it was found that explosibility from a drop-height of 337 cm. was only about 20%. The reason for this was likely the uneven distribution of energy to the thin charge. Energy dissipation likewise was encountered here. Since such results would place PETN in a class with TNT, it was decided to discontinue design 12-b.

As long as PETN charges were not flattened (as described) before impact, the material showed 100% explosibility at 100-125 cm. But this danger is apt to happen during any determination involving design 12-b.

TABLE XXX
DATA FOR LIQUIDS WITH DESIGN 13

Drop Height (cm)	NG ^o		80 NG-DGTC ^o		75 NG-DGTC ^o		70 NG-DGTC ^o		95 DEGN		90 DEGN		85 DEGN	
	Trials	%E	Trials	Ave. %E	Trials	Ave. %E	Trials	Ave. %E	Trials	Ave. %E	Trials	Ave. %E	Trials	Ave. %E
6	20	15												
8	20	80												
10	20	85	20	0										
12	20	75												
15	10	80	20	10										
20			20	15	20	0								
30			20	32.5	20	10								
40			20	60	20	60								
50			20	90	20	90								
60			20	100	20	100								
70														
75														
80														
100														
125														
150														
175														
200														

o Nitroglycerin
o Diethyl tetrastearate
o Dimethyl Phthalate
1 Diethylene glycol dinitrate
2 Diisobutylene

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TABLE XXXI

DATA FOR SOLID EXPLOSIVES FROM DESIGN NO. 13

Drop Height (Cm.)	Lead		PETN		Pentolite		RDX		Tetryl		Torped-2	
	T	%E _c	T	%E	T	%E*	T	%E	T	%E	T	%E
6	10	0										
8	20	0										
10	20	20										
15	20	85										
20	20	100	20	0			20	0			30	0
30			20	10	20	0	20	10			20	10
40			20	15	20	7.5	20	10	20	0	40	28.8
50			20	30	20	2.5	20	15	20	5	20	25
60			20	25	20	30						
70			20	60			20	15				
75					20	80			20	35	20	65
80			20	90					20	52.5		
90			20	80					20	77.5		
100			20	95	20	100	20	40	20	100	40	85
125							20	55			10	95
150							20	70				
175							20	70				
200							20	67.5				
250							20	90				
300							20	100				
337												

*%E for Pentolite and subsequent explosives is Ave. %E

Drop Height (Cm.)	Boron Torped		Minot-2		Comp. B		TNT		Picric Acid		Explosive D	
	T	%E	T	%E	T	%E	T	%E	T	%E	T	%E
6												
8												
10												
15												
20												
30	10	0										
40	20	2.5										
50	20	12.5	20	0	20	2.5	20	0				
60	20	42.5					20	0				
70												
75	20	97.5	20	22.5	20	7.5	40	10	20		0	
80												
90												
100	20	100	20	47.5	20	65	40	23.8	20	42.5	20	0
125									20	72.5		
150			20	97.5	20	85	40	48.8	20	85		
175									20	85		
200			10	100	20	97.5	40	40			20	0
250							40	48.8				
300					20	95	40	62.5			20	1.5
337							30	68.3			20	2.5

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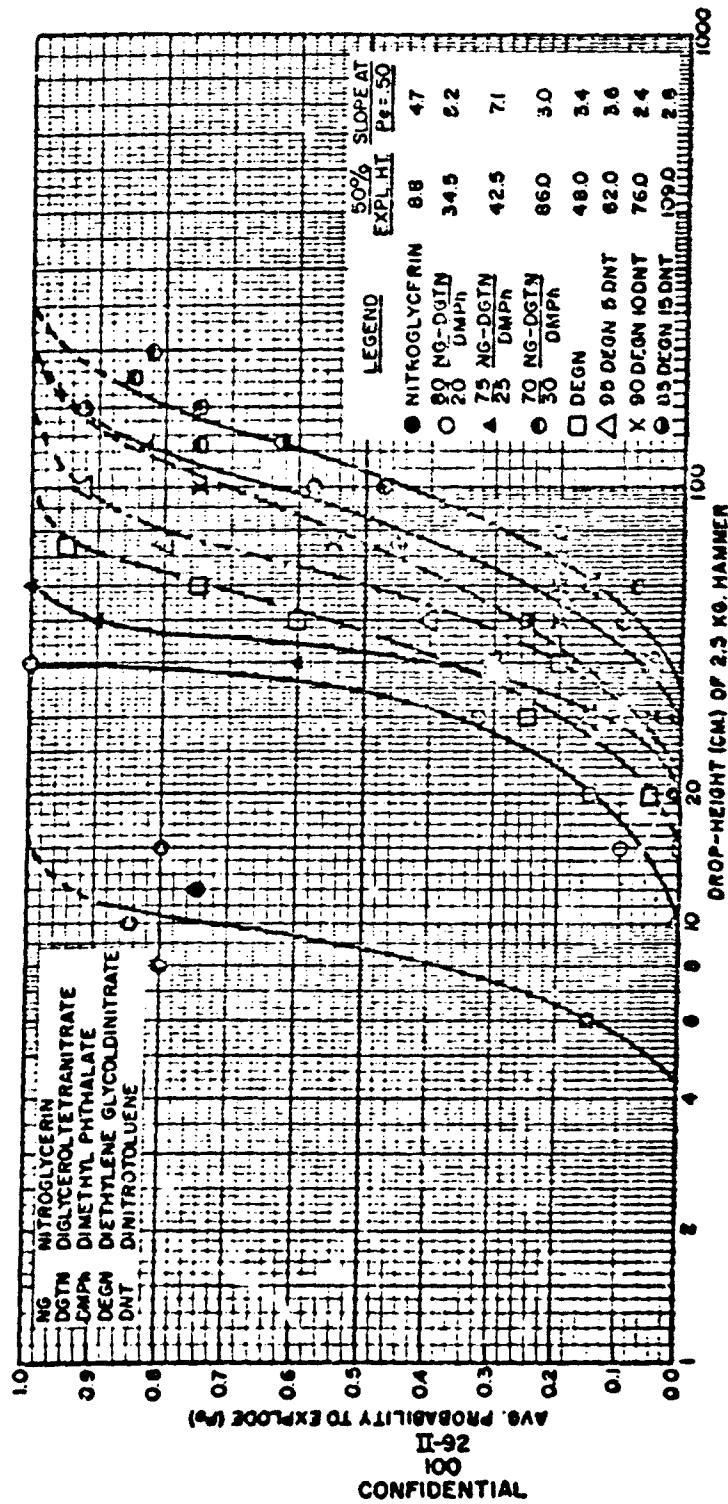


FIG. 26 COMPARATIVE PRACTICAL SENSITIVITIES OF LIQUIDS BY DESIGN NO. 13

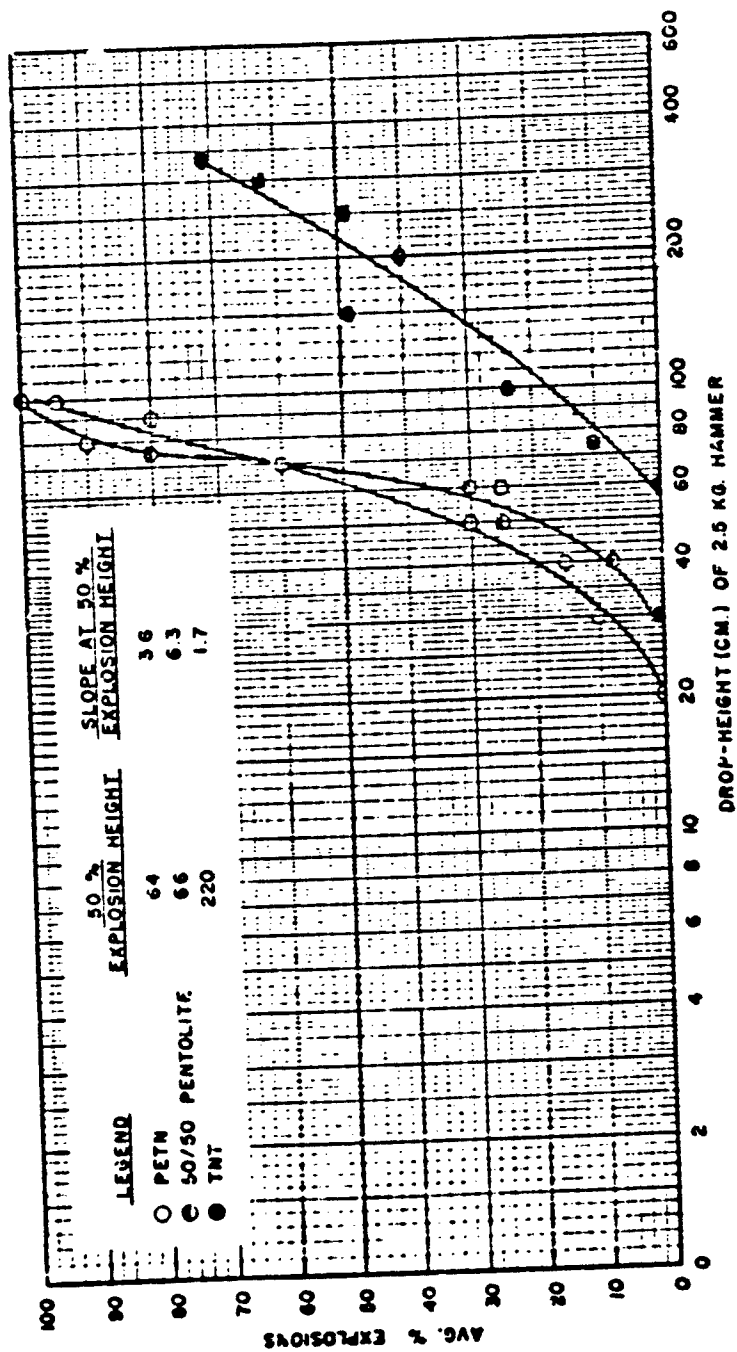


FIG. 27 COMPARATIVE PRACTICAL SENSITIVITIES BY DESIGN NO. 13

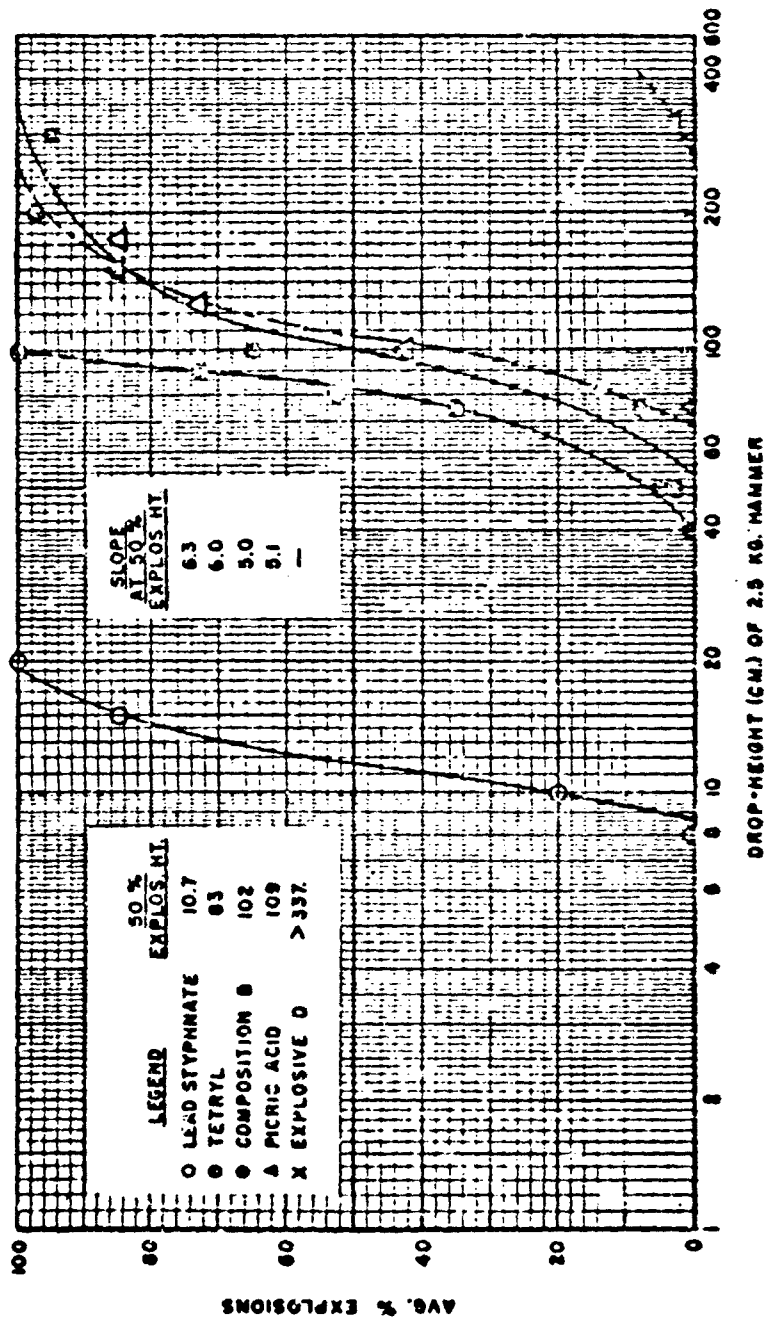


FIG. 28 COMPARATIVE PRACTICAL SENSITIVITIES BY DESIGN NO. 13

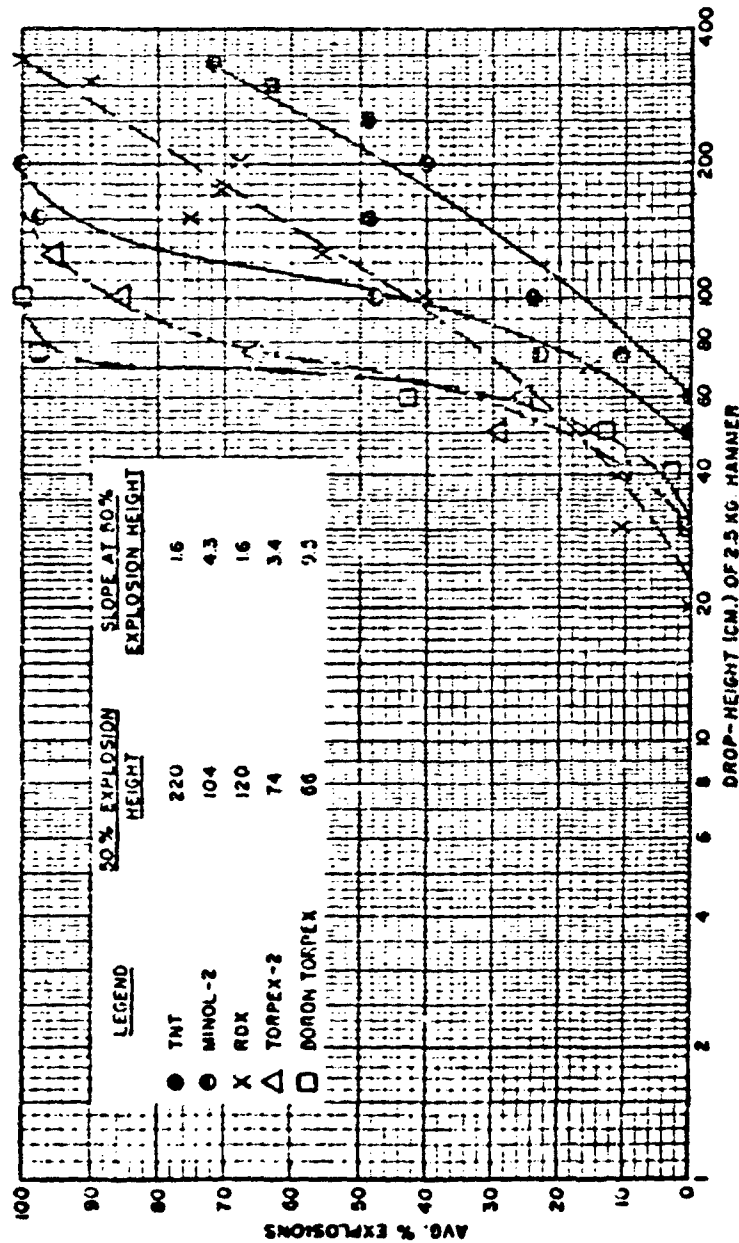


FIG. 29 COMPARATIVE PRACTICAL SENSITIVITIES BY DESIGN NO. 13

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TABLE XXXII

SUMMARY OF SIGNIFICANT GRAPHICAL DATA FOR CERTAIN LIQUID
EXPLOSIVES AS TESTED BY DESIGN NO. 13

Name of Explosive	50% Explosion Drop-Height (Cm.)	Evaluation of 50% Explosion Point on Basis of Nitroglycerin = 1.0	0% Explosion Drop-Height (Cm.)	Evaluation of 0% Explosion Point on Basis of Nitroglycerin = 1.0	100% Explosion Drop-Height	Evaluation of 100% Explosion Point on Basis of Nitroglycerin = 1.0	Average Evaluation on Basis of Nitroglycerin = 1.0
Nitroglycerin	8.8	1.0	4.4	1.0	16*	1.0	1.0
80/20 NG-DGTN/ D.M. Phthalate	34.5	3.9	10	2.3	40	2.5	2.9
75/25 NG-DGTN/ D.M. Phthalate	42.5	4.8	21	4.8	60	3.8	4.5
Diethyleneglycol- dinitrate (DEGN)	48	5.5	15.8	3.6	98*	6.1	5.1
95/5 DEGN/DNT	62	7.0	23	5.2	142*	8.9	7.0
90/10 DEGN/DNT	76	8.6	21	4.8	189*	11.8	8.4
70/30 NG-DGTN/ D.M. Phthalate	36	9.8	30	6.8	139*	11.8	9.5
85/15 DEGN/DNT	109	12.4	35	8.0	240*	15.0	11.8
*Extrapolated							

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TABLE XXXIII

SUMMARY OF SIGNIFICANT GRAPHICAL DATA FOR CERTAIN SOLID
EXPLOSIVES AS TESTED BY DESIGN NO. 13

Name of Explosive	Slope of Practical Curve at 50% Explosion Point	50% Explosion Drop-Height (Cm.)	Evaluation of 50% Explosion Height on Basis of TNT = 100	0% Explosion Drop-Height (Cm.)	Evaluation of 0% Explosion Point on Basis of TNT = 100	100% Explosion Drop-Height (Cm.)	Evaluation of 100% Explosion Point on Basis of TNT = 100	Average Evaluation on Basis of TNT = 100
Lead Styphnate	6.7	10.7	5	9.6	14	19	3	9
PETN	3.3	64	29	21	35	105*	17.5	27
Boron Torpex	8.1	66	30	33	55	92	15	33
50/50 Pentolite	7.1	66	30	30	50	98	16	32
Torpex-2	3.4	74	34	31	52	150*	25	37
Tetryl	7.6	83	38	40	67	100	17	41
Composition B	4.0	102	46	56	93	350	58	66
Minol-2	4.3	104	47	48	80	192	32	53
Picric Acid	5.1	109	49	70	117	242*	40	69
RDX	1.5	110	50	22	37	337	56	48
TNT	1.8	220	100	60	100	600*	100	100
Ammonium Picrate	--	>337	>100	270	450	>337	>100	>100

*Extrapolated

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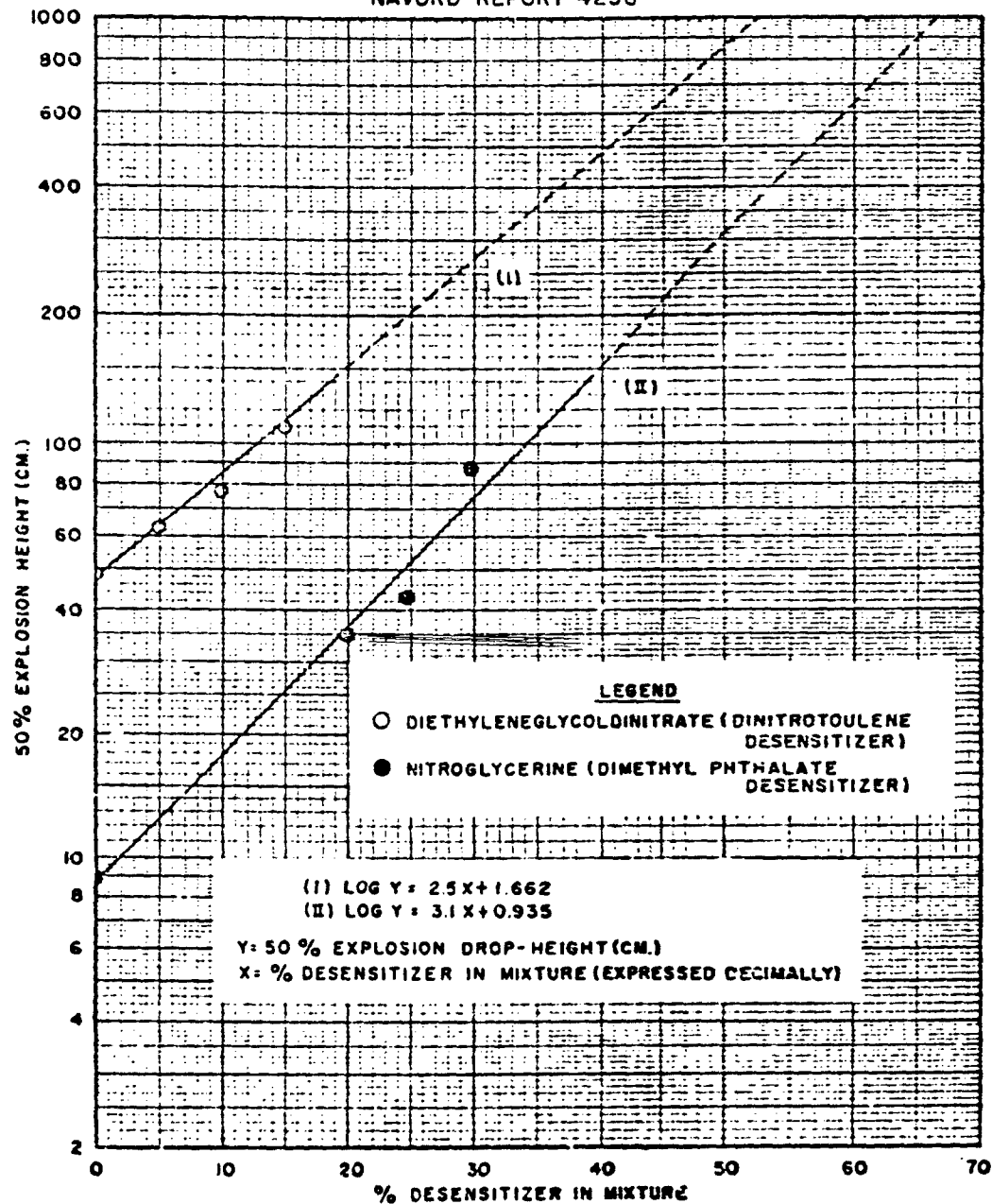


FIG. 30 THE EFFECT OF DESENSITIZER ON THE 50% EXPLOSION HEIGHTS OF NITROGLYCERINE AND DIETHYLENEGLYCOLDINITRATE AS TESTED BY DESIGN NO. 13

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A - PITTED ANVIL FROM EXPLOSIONS OF MERCURY FULMINATE

PLATE XII

DAMAGE TO LARGE STRIKERS BY POWERFUL EXPLOSIONS
OF NITROGLYCERIN, WHEN TESTED BY DESIGN 13.

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TABLE XXXIV

DATA OBTAINED BY DESIGN 12b

Drop Height (cm)	Lead		Mercury		PETN		Tetryl		Torpex-2		TNT		Comp B		Cast TNT	
	Trials	%Ec	Trials	%Ec	Trials	%Ec	Trials	%Ec	Trials	%Ec	Trials	%Ec	Trials	%Ec	Trials	%Ec
2	10	0	10	10												
4	10	30	10	40												
6	10	70	10	50												
8	10	90	10	70												
10	10	70	10	80												
15	10	100	10	100												
20					40	2.5										
30					20	5										
40					20	5										
50					60	38.8										
60					20	5										
75					20	35										
90					20	5										
100					20	100										
125							20	20	20	0	20	2.5				
150							20	50	20	15	20	7.5	20	0		
175							20	45	20	40	20	17.5	20	5		
200							20	67.5	20	40	20	17.5	20	15	20	0
225							20	80	20	42.5	40	28.8	20	15		
250							20	87.5	20	70	20	30	20	12.5		
275							20	100	20	80	40	42.5	20	7.5	20	5
300									20	92.5	20	60	40	32.5	40	16.2
325									20	100	20	52.5	40	32.5	40	
350											20	67.5				

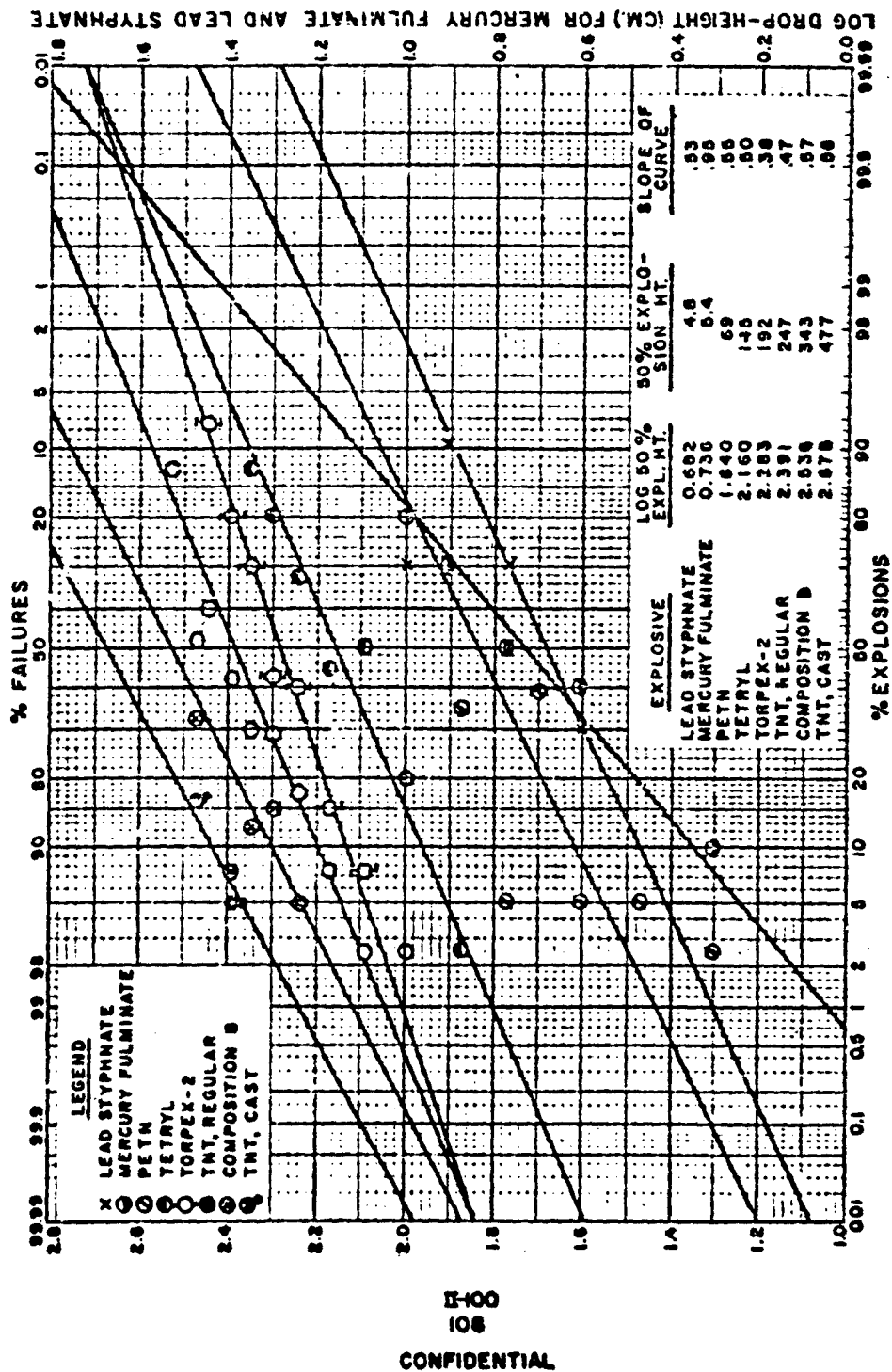


FIG. 31 COMPARATIVE SENSITIVITIES BY DESIGN NO. 12b

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In addition to determining the average % explosions at various drop-heights for design 13, a quantitative approach was attempted. The various qualitative types of explosions obtained were given arbitrary evaluations in an attempt to interpret the behavior of PETN and Pentolite as studied by design 13. From Figure 27 it is seen that the 50% explosion heights are 64 for PETN and 66 for Pentolite. Practically, these are vastly different because of the difference in the degree of intensity of explosions of these two explosives.

The procedure was as follows: arbitrary evaluations for various types of explosions became: on the basis of 5.0 for a complete detonation (E_c), $N = 0$, $D = 0.10$, $E_p = 0.50$, $E = 2.50$, $E_1 = 3.75$, $E_{\bar{c}} = 4.75$. These evaluations also represent the amount of material exploding, as experience has proven that a D represents about 2% of the charge as exploding, an E_p as about 10%, an E as about 50%, E_1 as 75%, $E_{\bar{c}}$ as 95% and E_c as 100% exploding.

The evaluation principle was then applied to conventional data of 20 or more trials per drop-height. Each type of explosion was multiplied by its evaluation to obtain a total evaluation, or ΣE_v . This total actually represented the average % of material exploding per trial at a given drop-height. By this scheme, the most sensitive of several substances tested at a given drop-height, would have a ΣE_v of 100.

The above approaches a gas measurement, but of course is entirely personal and represents only an approximation to an actual evaluation from a measure of the gas evolved during an explosion.

Table XXXV summarizes results from design 13 with the evaluation principle applied, while Figures 32-33 show ΣE_v as a function of the logarithm of the drop-height as plotted on probability graph paper. From these data, it is seen that PETN and Pentolite are in better order. RDX behaves out of line by design 13, and recently it has been decided to use this design for liquid explosives only.

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Drop-Height (cm.) of 2.5 Kg. Hammer	Lead Styphnate									PETN									Tetryl			
	E _p	E	E ₁	E _g	E _c	D	N	ΣE _v		E _p	E	E ₁	E _g	E _c	D	N	ΣE _v		E _p	E	E ₁	E _g
6	0	0	0	0	0	0	10	0														
8	0	0	0	0	0	0	20	0														
10	0	0	0	0	0	0	16	20														
15	0	0	0	0	17	0	3	85		-	-	-	-	-	-	-	-					
20	0	0	0	0	20	0	0	100		0	0	0	0	0	0	20	0					
30	-	-	-	-	-	-	-	-		0	1	1	0	0	0	18	6.3		-	-	-	-
40										0	0	1	0	2	0	17	13.8		0	0	0	0
50										0	0	0	1	5	0	14	29.8		0	1	0	0
60										0	0	0	2	3	0	14	24.5		-	-	-	-
70										0	0	0	2	10	0	8	59.5		-	-	-	-
75										-	-	-	-	-	-	-	-		0	2	4	0
80										0	0	0	4	14	0	2	89		0	2	8	0
90										0	0	0	4	12	0	4	79		0	2	13	0
100										0	0	0	3	16	0	1	94.3		0	2	18	0
125										-	-	-	-	-	-	-	-					

Drop-Height (cm.) of 2.5 Kg. Hammer	Picric Acid									Minol-2									RDX			
	E _p	E	E ₁	E _g	E _c	D	N	ΣE _v		E _p	E	E ₁	E _g	E _c	D	N	ΣE _v		E _p	E	E ₁	E _g
20																			0	0	0	0
30																			0	0	2	0
40																			0	0	2	0
50										0	0	0	0	0	0	20	0		0	0	3	0
60										-	-	-	-	-	-	-	-		-	-	-	-
70	-	-	-	-	-	-	-	-		-	-	-	-	-	-	-	-		0	0	3	0
75	0	0	0	0	0	0	20	0		0	0	0	0	0	9	11	.9		-	-	-	-
100	0	6	1	0	0	3	10	19.1		2	4	0	0	0	7	7	11.7		0	0	6	14
125	0	5	9	0	0	1	5	46.4		-	-	-	-	-	-	-	-		0	0	0	11
150	0	5	10	0	0	4	1	50.4		3	8	8	0	0	1	0	51.6		0	1	2	11
175	1	4	11	0	0	2	2	52		-	-	-	-	-	-	-	-		0	0	1	37
200										2	3	5	0	0	0	0	54.6		0	1	3	22
250																			-	-	-	-
300																			0	0	0	18
337																			0	0	0	15

N	IE _v	Tetryl								Pentolite								Torpedex -2							
		E _p	E	E ₁	E ₂	E _c	D	N	IE _v	E _p	E	E ₁	E ₂	E _c	D	N	IE _v	E _p	E	E ₁	E ₂	E _c	D	N	IE _v
-	-																								
20	0																								
18	6.3	-	-	-	-	-	-	-	-	0	0	0	0	0	0	20	3	0	0	0	0	0	0	30	0
17	13.8	0	0	0	0	0	0	10	0	0	0	0	0	0	3	17	.3	0	0	0	0	0	5	25	.5
14	29.8	0	1	0	0	0	0	19	2.5	0	3	0	0	0	4	13	7.9	1	1	0	0	0	13	19	3.2
14	24.5	-	-	-	-	-	-	-	-	0	3	0	0	0	6	11	8.1	2	0	0	0	0	6	12	1.6
8	59.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	0	2	4	0	0	2	12	20.2	0	13	2	0	0	2	3	47.9	3	6	1	0	0	6	4	20.9
2	89	0	2	8	0	0	1	9	35.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4	79	0	2	13	0	0	1	4	53.9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1	94.3	0	2	16	0	0	0	0	72.5	1	10	9	0	0	0	0	59.3	6	22	3	0	0	6	3	36.1
-	-																	0	0	9	0	0	1	0	67.8

N	IE _v	RDX								Composition B								TNT							
		E _p	E	E ₁	E ₂	E _c	D	N	IE _v	E _p	E	E ₁	E ₂	E _c	D	N	IE _v	E _p	E	E ₁	E ₂	E _c	D	N	IE _v
		0	0	0	0	0	0	20	0																
		0	0	2	0	0	0	18	7.5																
		0	0	2	0	0	0	18	7.5																
20	0	0	0	3	0	0	0	17	11.3	0	0	0	0	0	1	19	.1	0	0	0	0	0	0	20	0
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	0	20	0
-	-	0	0	3	0	0	0	17	11.3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
11	.9	-	-	-	-	-	-	-	-	0	0	0	0	0	3	17	.3	1	0	0	0	0	6	33	.6
7	11.7	0	0	6	14	4	0	36	36.3	0	9	0	0	0	8	3	13.3	0	6	0	0	0	7	27	7.9
-	-	0	0	0	11	0	0	9	52.3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0	51.6	0	1	2	11	0	0	14	62.3	0	8	8	0	0	2	2	50.2	0	14	0	0	0	11	15	18.1
-	-	0	0	1	37	4	0	18	66.7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0	54.6	0	1	3	22	1	0	27	62.3	0	6	13	0	0	1	0	63.9	0	10	0	0	0	12	18	13.1
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	12	2	0	0	9	16	19.5
		0	0	0	18	0	0	2	85.5	0	2	7	0	0	1	0	62.8	0	19	2	0	0	8	11	27.9
		0	0	0	15	3	0	0	96.2									1	15	0	0	0	9	3	25.9

TABLE XXIV
SUMMARY OF DESIGN 33 EVALUATION DATA (SOLIDS)

2

PETN						Tetryl								Pentolite								T		
E ₁	E ₂	E ₃	D	N	ΣE _v	E _p	E	E ₁	E ₂	E ₃	D	N	ΣE _v	E _p	E	E ₁	E ₂	E ₃	D	N	ΣE _v	E _p	E	E ₁
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0	0	0	0	20	0									-	-	-	-	-	-	-	-	-	-	-
1	0	0	0	18	6.3	-	-	-	-	-	-	-	-	0	0	0	0	0	0	20	0	0	0	0
1	0	2	0	17	13.8	0	0	0	0	0	0	10	0	0	0	0	0	0	3	17	.3	0	0	0
0	1	5	0	14	29.8	0	1	0	0	0	0	19	2.5	0	3	0	0	0	4	13	7.9	1	1	0
0	2	3	0	14	24.5	-	-	-	-	-	-	-	-	0	3	0	0	0	6	11	8.1	2	0	0
0	2	10	0	8	59.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	0	2	4	0	0	2	12	20.2	0	13	2	0	0	2	3	47.9	3	6	1
0	4	14	0	2	89	0	2	8	0	0	1	9	35.1	-	-	-	-	-	-	-	-	-	-	-
0	4	12	0	4	75	0	2	13	0	0	1	4	53.9	-	-	-	-	-	-	-	-	-	-	-
0	3	16	0	1	94.3	0	2	18	0	0	0	0	72.5	1	10	9	0	0	0	0	59.3	6	22	3
-	-	-	-	-	-																	0	0	9

Minol-2							RDX							Composition B												
E ₁	E ₂	E ₃	D	N	ΣE _v		E _p	E	E ₁	E ₂	E ₃	D	N	ΣE _v	E _p	E	E ₁	E ₂	E ₃	D	N	ΣE _v	E _p	E	E ₁	
							3	0	0	0	0	0	20	0												
							0	0	2	0	0	0	18	7.5												
							0	0	2	0	0	0	18	7.5												
0	0	0	0	20	0		0	0	3	0	0	0	17	11.3	0	0	0	0	0	1	19	.1	0	0		
-	-	-	-	-	-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	
-	-	-	-	-	-		0	0	3	0	0	0	17	11.3	-	-	-	-	-	-	-	-	-	-	-	-
0	0	0	9	11	.9		-	-	-	-	-	-	-	-	0	0	0	0	0	3	17	.3	1	0		
0	0	0	7	7	11.7		0	0	6	14	4	0	36	36.3	0	9	0	0	0	8	3	23.3	0	6		
-	-	-	-	-	-		0	0	0	11	0	0	9	52.3	-	-	-	-	-	-	-	-	-	-	-	-
8	0	0	1	0	51.6		0	1	2	11	0	0	14	62.3	0	8	8	0	0	2	2	50.2	0	14		
-	-	-	-	-	-		0	0	1	37	4	0	18	66.7	-	-	-	-	-	-	-	-	-	-	-	-
3	0	0	0	0	54.6		0	1	3	22	1	0	27	62.3	0	6	13	0	0	1	0	63.9	0	10		
							-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	12	
							0	0	0	18	0	0	2	85.5	0	2	7	0	0	1	0	62.8	0	19		
							0	0	0	15	5	0	0	96.2									1	15		

TABLE XXV
SUMMARY OF DESIGN 13 EVALUATION DATA (SOLIDS)

		Torrex -2								Boron Torrex								Drop-Height (ca.) of 2.5 Kg. Hammer
N	IE _v	E _p	E	E ₁	E ₂	E _c	D	N	IE _v	E _p	E	E ₁	E ₂	E _c	D	N	IE _v	
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	8
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	15
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	23
20	0	0	0	0	0	0	0	30	0	0	0	0	0	0	0	10	0	30
17	.3	0	0	0	0	0	5	25	.5	0	0	0	0	0	1	19	.1	40
13	7.9	1	1	0	0	0	19	19	3.2	1	0	0	0	0	3	16	.8	50
11	8.1	2	0	0	0	0	6	12	1.6	2	3	0	0	0	7	8	9.2	60
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	70
3	47.9	3	6	1	0	0	6	4	20.9	1	13	5	0	0	1	0	51.9	75
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	80
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	90
0	59.3	6	22	3	0	0	6	3	36.1	0	8	12	0	0	0	0	65	100
-	-	0	0	9	0	0	1	0	67.8	-	-	-	-	-	-	-	-	125

2

			INT							Ammonium Picrate							Drop-Height (cm.) of 2.5 Kg. Hammer		
D	N	IE _v	E _p	E	E ₁	E ₂	E _c	D	N	IE _v	E _p	E	E ₁	E ₂	E _c	D		N	IE _v
																			20
																			30
																			40
1	19	.1	0	0	0	0	0	0	20	0									50
-	-	-	0	0	0	0	0	0	20	0									60
-	-	-	-	-	-	-	-	-	-	-									70
3	17	.3	1	0	0	0	0	6	33	.6	-	-	-	-	-	-	-	-	75
8	3	23.3	0	6	0	0	0	7	27	7.9	0	0	0	0	0	0	20	0	100
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	125
2	2	50.2	0	10	0	0	0	11	15	18.1	-	-	-	-	-	-	-	-	150
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	175
1	0	63.9	0	10	0	0	0	12	18	13.1	0	0	0	0	0	0	20	0	200
-	-	-	1	12	2	0	0	9	16	19.5	-	-	-	-	-	-	-	-	250
1	0	62.8	0	19	2	0	0	8	11	27.9	0	1	0	0	0	1	16	2.6	300
			1	15	0	0	0	9	5	25.9	2	0	0	0	0	1	17	1.1	337

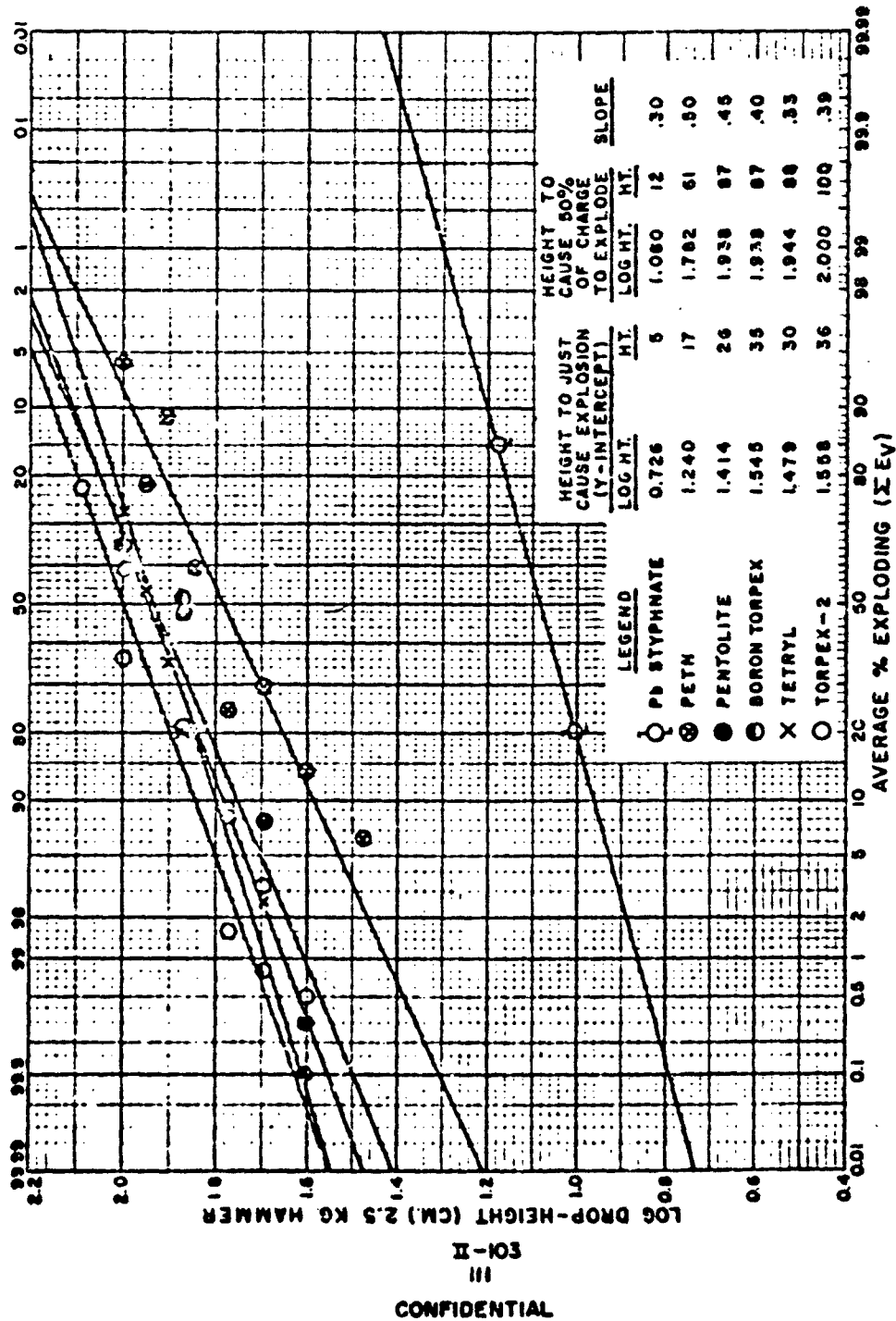


FIG. 32 SENSITIVITIES BY DESIGN NO. 13 WITH EVALUATION APPLIED

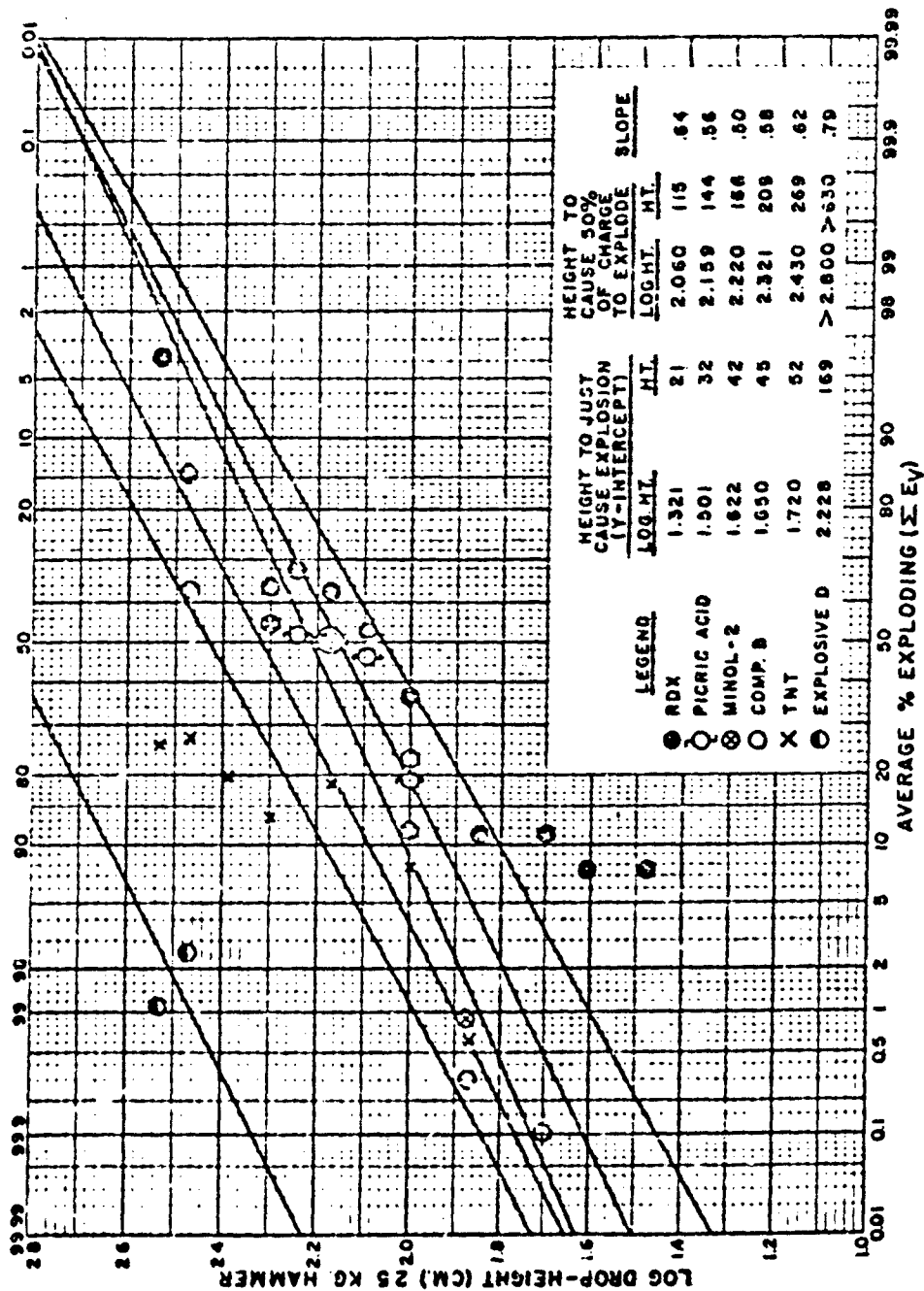


FIG 33 SENSITIVITIES BY DESIGN NO.13 WITH EVALUATION APPLIED

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Concluding Remarks:

By way of evaluating various designs we may conclude that Nos. 3, 12 and 13 are the most satisfactory at the present writing. The No. 3 is satisfactory for comparing materials in the low and intermediate levels of sensitivity, the No. 12 is satisfactory for comparing insensitive materials, while the No. 13 seems fairly satisfactory for investigating comparative behavior of liquid explosives. Other designs all contain disadvantages which caused a discontinuation of each.

As for future work, a newer approach to sensitivity work may be attempted. To obtain better reproducibility in impacts, it is hoped that an inverted pendulum type of machine will suffice. The idea arose after an unfortunate conclusion that the falling weight machine possesses, by nature, uncontrollable deviations in the form of irreproducibility of impacts as the hammer hits the striker. These slight differences are shown earlier in the form of 10 successive imprints. The new machine, if equipped with excellent bearings for the arm of the drop-hammer and also proper facilities to obtain good alignment of hammer and anvil surfaces, should produce more reproducible impacts. This type of machine also gives a practical test in that the explosive is struck directly by the guided weight corresponding to the blow of a claw hammer or a sledge hammer, depending upon the mass of the proposed weight. Such a machine could be used for testing any types of explosive, i. e., solid, liquid, molten or frozen material.

Another idea for future consideration is the substitution of 3/4" diameter abrasive-coated metal discs for the flint paper of design 12. It is hoped that the reaction of certain oxidizing agents with the paper base of the flint paper will be thereby removed.

It is likewise hoped that the measurement of the gas evolved during explosions from impact may be carried out in the near future.

It is this writer's opinion that solid explosives will show deviations regardless of the method of testing. The elastic properties of a given solid explosive seem to be the important factor in impact. Hard, brittle, inelastic substances are usually sensitive to impact; while soft, waxy, elastic substances appear in the intermediate and insensitive categories. The pressure rise during impact is rapid and reaches an enormous maximum value. The maximum pressure is

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dependent upon the modulus of elasticity of the substance receiving impact. With steel, these pressures are reproducible, as the modulus of elasticity is constant. However, with explosives, variations in pressure occur while investigating the same substance, as the elastic properties vary throughout the mass. Each scoop of a given explosive may vary as to its modulus of elasticity; and as a result, different pressures of impact are produced even though the hammer be dropped from a given height for successive trials. The pressure variations together with the non-uniform impacts of the hammer against the striker, will account for variations in the form of doubtful, partial, common, loud and complete explosions all occurring at a constant drop-height and also the irreproducibility of the same number of each type if a given series be repeated.

The pressure variations due to divergences of the modulus of elasticity are most likely minimized in the case of liquid explosives, as elastic properties are more nearly uniform here. In general, liquids will explode with greater intensity than solids. This seems logical, as in liquids the molecules are more compact and once the explosive chain reaction be initiated, it can continue with greater ease; whereas with solids, the gaps between individual molecules tend to hinder propagation and less intensive explosions are produced. Past experience has shown that solid explosives are usually slightly more sensitive when in a fine state of subdivision. This likewise seems logical in that molecules are slowly approaching compactness and a liquid in behavior as the subdivisions become finer and finer.

The unfortunate conclusion concerning solids is that at best we will have to be content with comparative data representing an average value of the limit of the true value.

Rogers F. Davis

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REPORT III

Bruceton, Pa.
August 7, 1944

Report to: Dr. E. H. Eyster
From: Rogers F. Davis
Subject: Supplement to Reports of March 13, 1944 and
July 4, 1944 Concerning Bruceton Design No. 12
for Studying the Behavior of Explosives to Impact

This present report is to discuss recently acquired data with Design No. 12 and also to present the probability plots of other available data by the same design.

The procedure involved with Design No. 12 was discussed in the report of March 13, 1944 (Copies: Dr. D. P. MacDougall and Dr. J. C. Holtz); however, a brief review cannot be harmful. The method involves the use of a 1 1/4" diameter Ketos steel striker of 3 1/2 - 3 11/16" in length and the usual Ketos anvils of 1 1/4" diameter and 2-2 1/2" in height. Illustrations of the design are shown in Plates I and II.

The sample of explosive, measured volumetrically by means of a small scoop or spoon of 17-18 mm³ volume, is placed atop a 1/2" square of 5/0 Armour flint paper, which in turn is centered atop the 1 1/4" diameter anvil. The large striker is pressed atop the flint paper-explosive combination and tamped gently by a 1/2 cm. drop of the 2.5 kilogram weight or drop-hammer. The tamping procedure is to present a nearly constant surface of crystals to receive the impact.

Explosives are investigated by the so-called conventional procedure, i. e., at least 20 trials are carried out for various drop-heights to obtain 0-100% explosibility.

The practical elongated S-shaped curves of some 42 explosives were shown in the March 13 report. These curves are obtained by plotting the average % explosions as a function of the logarithm of the drop-height on semi-logarithmic coordinate paper. The newer interpretation involving probability graph paper is shown in the present writing.

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Table I shows in summary form the data used in the March 13 report. It is a photograph of the large table appearing in this previous writing.

Tables II - V show actual data for 42 explosives investigated during August-October, 1943. These explosives are divided into four classes according to their sensitiveness. The classification is based not entirely upon the 50% explosion drop-heights, but on the overall curve for each explosive.

Table VI presents actual data for seven explosives of a common particle size. These seven are not to be compared with any of the 42 other substances, as the particle sizes are much different. The latter seven explosives represent a coarse grained material and are to be compared with each other only.

Figures 1-8 show the probability plots of data from Tables II - V. The average % explosions is plotted as a function of the logarithm of the drop-height. These values are obtained by treating D or doubtful explosions as 1/2 explosions (see page II-83-91).

Figures 11-17 show probability plots of data from Tables II-V obtained by treating doubtful explosions as failures, i. e., plotting % explosions only. These plots are made to reveal the 50% explosion drop-heights only.

Figures 9, 10 and 18, 19 treat data from Table VI in an identical manner.

Table VII summarizes the graphical 50% explosion drop-heights of 42 explosives as determined from probability plots of actual data from Tables II-V. Two 50% explosion heights are listed, namely, that for average % explosions and for % explosions only (doubtful explosions being treated as failures to explode). These 50% explosion heights are also converted to an evaluation scale with TNT set as the standard at 100 units. Table VIII shows a direct comparison of the two evaluated 50% explosion heights. It is seen that the same orders and values (TNT values), with few exceptions, exist.

These comparisons were made because it has often been the opinion to note doubtful explosions, but to actually sum them as failures. To sum doubtfuls as explosions would change the practical

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sensitivity order; and it is not fair or sensible from a practical viewpoint, because doubtfuls are very low order "explosions".

Table IX shows the graphical data for the seven coarse grained explosives, with TNT evaluations applied and compared.

An early argument against Design No. 12 was that it could not be used to determine the effect of added grit upon the sensitivity of a given explosive. It was argued that the presence of grit in the 5/0 flint paper would nullify any sensitizing effects of grit within the explosive. A study of the effect of added grit upon the sensitivity of RDX and TNT was recently completed with the employment of the No. 12 design. It was encouraging to find that the presence of >1% grit was easily detected. Table X summarizes these data, while Figures 20-23, 25-28 treat these data graphically. Figures 24 and 29 show the 50% average explosion drop-height of TNT and RDX plotted as a function of the % of grit in the explosive. The curves obtained are as expected, indicating a maximum sensitiveness is reached when about 20% grit is present. Two particle sizes of grit were used during the study, but both gave approximately the same sensitizing effect in magnitude and general behavior. As the % of grit to cause greatest sensitiveness was exceeded, the curve again rises to an extrapolated infinite drop-height for 100% grit.

The 50% explosion height for TNT without grit is somewhat above normal, but these data were obtained by a different observer than for the reference curve of Figure 8. Too, recent data indicate that TNT is apt to vary in its 50% explosion height from 75-95 cm., depending upon the observer. The difficulty here is in the interpretation of certain trials as doubtful explosions or as partial explosions.

Results from Design No. 12 are in general reproducible. Tabulated below are 50% explosion drop-heights for 12 Canadian samples recently tested compared with 50% explosion drop-heights taken from Table VII. These explosives were examined by the same observer, although the samples were different.

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<u>Explosive</u>	<u>Recent Data</u>	<u>Table VII Data</u>
PETN	8	9.5
Blasting Gelatin	13	---
RDX	15	15
NENO	13	23
DINA	25	25
Pentolite	26	32
EDNA	34	31.5
Tetryl	37	32
Picric Acid	46	36
MNO	50	66.5
Composition B	56	55
TNT	79	75

Another variable recently studied with Design No. 12 was the effect of the weight of material tested upon the drop-heights necessary to cause explosions. Data for this study are seen for RDX and TNT in Table XI. Graphical treatment is seen in Figures 30, 32. Figures 31, 33 show the 50% explosion drop-heights as a function of the weight of material tested.

For TNT it is seen that lower 50% explosion heights are obtained with small samples; and as the layer of explosive becomes thicker, the drop-height must be increased. The same effect for RDX was not displayed until >50 mg. charges were tested.

From data of Table XI it is seen that the greatest effect of the weight of sample appears at the <50% explosibility side of the curve, while the effect disappears at drop-heights to cause >50-75% explosibility.

It was shown in the report of July 4, 1944 (see page II-83-91) that reaction between oxygen-rich explosives and the paper base of the 5/0 flint paper does occur. Such a phenomenon should be considered when studying this type of explosive compound. The use of metal discs coated with abrasive would undoubtedly eliminate these reactions. Such procedure is for future consideration.

Now that sufficient data are available, it may be said that Design No. 12 appears to be suitable for practically all solid explosives. The

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order of sensitivity obtained by this design appears reasonable from the practical viewpoint.

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A = KETOS STEEL ANVIL OF 1-1/4" DIAMETER

C = CHARGE OF EXPLOSIVE ATOP 1/2" SQUARE OF 5/0 FLINT PAPER

G = GUIDE RING FOR 1-1/4" DIAMETER STRIKER

R = DEVICE TO CATCH DROP-HAMMER ON REBOUND

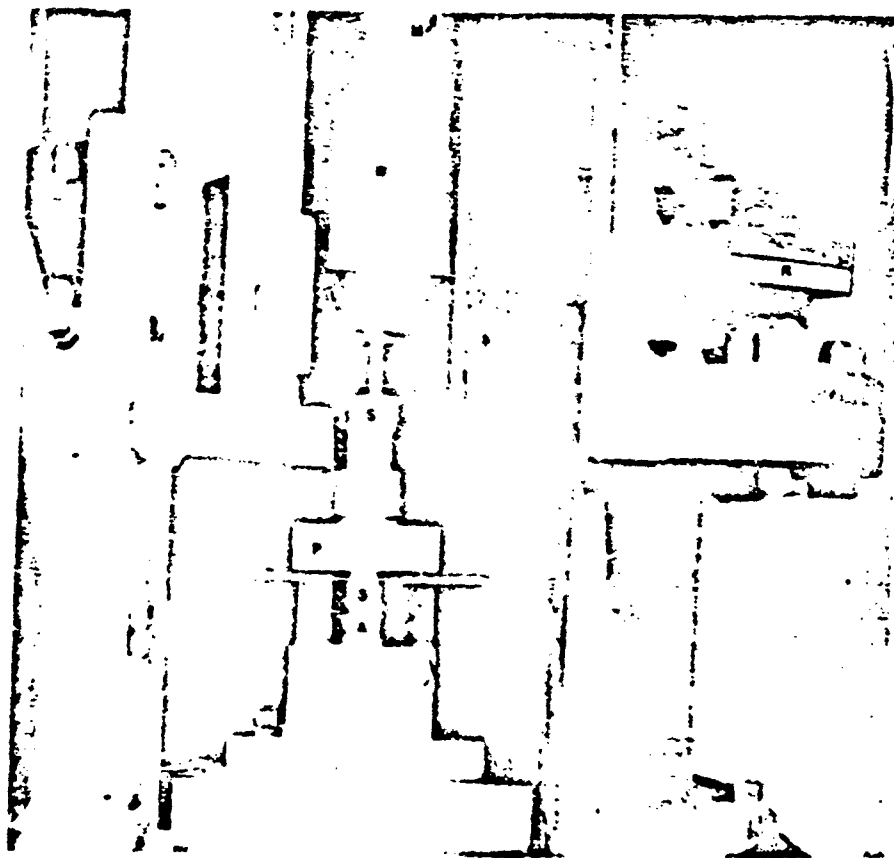
PLATE I
METHOD OF LOADING FOR DESIGN NO. 12

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- A = KETOS STEEL ANVIL OF 1-1/4" DIAMETER.
- P = SPIKE OR PIN TO PREVENT STRIKER'S ESCAPE FOLLOWING IMPACT FROM A DROP OF > 125 CM. OF THE DROP-HAMMER.
- S = 1-1/4" DIAMETER, 3-1/2" LONG KETOS STEEL STRIKER OR PLUNGER.
- W = 2.5 KILOGRAM DROP-HAMMER OR WEIGHT.
- M = ELECTROMAGNETIC DEVICE TO HOLD AND RELEASE THE WEIGHT OR DROP-HAMMER.
- R = DEVICE TO CATCH DROP-HAMMER ON REBOUND

PLATE II
THE DESIGN NO.12 WITH CHARGE READY TO RECEIVE IMPACT

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Number	Common Name of Explosive	Brucellin Designation or Code	Average Weight of Charge (mg.)	Height (cm.) for 0% D or E	Height (inches) for 0% D or E	Order on Basis of 0% D or E	Evaluation on Basis of 0% D or E for TNT-100	Minimum Height (cm.) to Produce D or Doubtful Explosion	Minimum Height (inches) to Produce D or Doubtful Explosion	% D at Minimum Height	Order on Basis of Minimum Height to Produce D	Evaluation on Basis of Minimum Height to Produce D for TNT-100	Minimum Height (cm.) to Produce E or Explosion	Minimum Height (inches) to Produce E or Explosion	% E at Minimum Height	Order on Basis of Minimum Height to Produce E or Explosion	Evaluation on Basis of Minimum Height to Produce E for TNT-100	Height (cm.) to Produce 50% Explosions
1	Erythritol Tetranitrate	R-476		2	0.8	1	13	(1.4)	(1.4)	No D or E	2	20	4	1.6	25.0	2	13	4.9
2	Nitromethane	R-2044	11.5	2	0.8	1	13	(1.4)	(1.4)	No D or E	1	20	4	1.6	37.5	1	13	4.9
3	4-HMX-RDX Mixture	R-2025	18.5	2	0.8	1	13	(1.4)	(1.4)	No D or E	3	20	6	1.6	10.0	1	13	8.1
4	Tetracene	(Mr. Graubow)	15.8	4	1.6	2	27	(2.4)	(2.4)	No D or E	4	30	6	2.4	20.0	4	20	7.3
5	PETN	R-1797	33.9	4	1.6	2	27	(2.4)	(2.4)	No D or E	5	30	6	2.4	15.0	5	20	10.0
6	Anhydrous azepitrol Permethate	R-1119-A		4	1.6	2	27	6	2.4	5.0	6	30	10	3.9	10.0	6	23	10.3
7	4-HMX	R-1863	28.5	6	2.4	3	40	8	3.1	7.5	7	40	8	3.1	2.5	7	27	15.9
8	50/50 PETN-Fivonite	R-1110	27.9	6	2.4	3	40	10	3.9	10.0	10	50	8	3.1	5.0	6	27	16.7
9	RDX	R-1748-B	26.1	6	2.4	3	40	12	4.7	7.5	13	50	8	3.1	5.0	6	27	15.7
10	EDNA	R-1046	43.1	6	2.4	3	40	8	3.1	2.5	9	40	10	3.9	2.5	9	23	28.0
11	NENO	R-1770-A	19.1	6	2.4	3	40	8	3.1	2.5	6	40	12	5.9	10.0	11	50	23.0
12	50/50 RDX-Fivonite	R-1672	31.5	8	3.1	4	51	10	3.9	9.0	11	50	15	5.9	10.0	11	50	25.0
13	50/50 EDNA-Fivonite	R-1748-B	18.9	8	3.1	4	51	10	3.9	2.5	12	50	20	7.9	2.5	16	61	35.0
14	Fivonite	R-1704	22.3	10	3.9	5	67	15	5.9	12.5	14	75	15	5.9	15.0	10	50	26.0
15	Barnal	R-1622	45.8	10	3.9	5	67	15	5.9	5.0	18	75	15	5.9	15.0	13	50	28.0
16	EDNA	50-BuNO ₂ 2, 15																
17	50/50 Fivonite	R-1704	15.3	10	3.9	5	67	15	5.9	5.0	18	75	15	5.9	5.0	13	50	33.0
18	Torpen-1	R-1796	18.5	10	3.9	5	67	15	5.9	20.0	15	75	20	7.9	10.0	14	67	33.6
19	Picric Acid	45R-1975	10.2	10	3.9	5	67	15	5.9	2.5	15	75	20	7.9	10.0	14	67	30.0
20	Tetrol	37R-1628, 18 Al	12.8	10	3.9	5	67	15	5.9	3.0	18	75	15	5.9	7.5	12	50	42.0
21	Emmet	R-1641	40.4	10	3.9	5	67	15	5.9	12.5	16	75	15	5.9	15.0	13	50	40.0
22	75/25 Tetrym	R-1745	14.0	10	3.9	5	67	20	7.9	3.3	22	100	15	5.9	5.0	13	50	41.0
23	Suzonite	75R-139 (fine)	26.9	10	3.9	5	67	15	5.9	10.0	17	75	20	7.9	15.0	13	67	41.0
24	50/50 Ednatol	25R-1628	23.3	10	3.9	5	67	15	5.9	2.5	18	75	20	7.9	7.5	15	57	48.0
25	Miscel-2	R-1626	28.3	10	3.9	5	67	15	5.9	5.0	18	75	20	11.8	15.0	22	100	60.0
26	Composite Propellant	R-1706	29.4	10	3.9	5	67	20	11.8	5.0	24	150	15	5.9	5.0	13	50	46.0
27	MNO	40 R-1628																
28	Ammonium Perchlorate	60NH ₄ NO ₃ 20 Al	33.4	15	5.9	6	100	20	7.9	5.0	20	100	20	11.8	25.0	21	100	44.0
29	Triazobenzene	R-128-M	10.6	10	3.9	5	67	15	5.9	2.5	18	75	20	11.8	10.0	23	100	78.0
30	50/50 Amatz	R-917	19.9	20	7.9	7	133	25	9.9	10.0	21	125	25	9.9	5.0	19	81	34.8
31	1, 3, 5, 8 Tetranitro-naphthalene	R-984	24.3	15	5.9	6	100	20	7.9	5.3	21	100	20	11.8	6.7	24	100	62.2
32	TNT	R-1624	25.1	15	5.9	6	100	20	7.9	5.0	20	100	20	11.8	30.0	20	100	56.0
33	British Composition A	R-916	29.1	15	5.9	6	100	20	7.9	15.0	19	100	20	11.8	15.0	22	100	70.0
34	1, 3, 5-Trinitro-naphthalene	NH ₄ NO ₃ (fine)	23.6	15	5.9	6	100	20	7.9	5.0	20	100	40	15.7	5.0	29	133	71.0
35	Ammonium Picrate	R-1628	23.3	15	5.9	6	100	20	7.9	2.5	22	100	30	11.8	3.3	25	100	20.0
36	Diammonium Picrate	R-1628	27.3	15	5.9	5	100	20	7.9	2.5	22	100	40	15.7	20.0	27	133	71.0
37	Potassium Chlorate	R-417	24.0	20	7.9	7	133	30	11.8	5.0	24	150	40	15.7	15.0	28	133	70.0
38	on 200 mesh	R-37																
39	Ammonium Nitrate	R-693-A	18.0	25	9.9	8	167	30	11.8	2.5	23	150	40	15.7	4.5	30	133	86.3
40	Potassium Perchlorate	R-1128	11.8	30	11.8	9	200	40	15.7	10.0	26	200	40	15.7	25.0	26	133	65.0
41	Thru 200 mesh	KClO ₄	30.6	30	11.8	9	200	40	15.7	5.0	27	200	40	15.7	5.0	29	133	110
42	Nitroguanidine	NH ₄ NO ₃	34.2	75	29.5	11	500	100	19.4	9.0	28	500	100	39.6	9.0	31	333	221
43	Quinidine Nitrate	KClO ₄	32.2	75	29.5	10	334	100	19.4	9.0	28	500	150	59.0	10.0	32	500	334
44		R-750	11.7	100	39.4	12	667	200	28.8	10.0	29	1000	157	132.5	10.0	33	1123	>133
45		R-1007	26.3	337	132.5	13	2746	337	132.5	0.0	30	1585	337	132.5	0.0	34	9123	>133

TABLE I

	Produce E or Explosion Minimum Height (inches) to Produce E or Explosion	% E at Minimum Height	Order on Basis of Minimum Height to Produce E or Explosion	Evaluation on Basis of Minimum Height to Produce E for TNT-100	Height (in.) to Produce 50% Explosions	Height (inches) to Produce 50% Explosions	Order on Basis of Height to Produce 50% Explosions	Evaluation on Basis of Height for 50% Explosions for TNT-100	Height (in.) to Produce 100% Explosions	Height (inches) to Produce 100% Explosions	Height (in.) to Produce 100% Explosions	Order on Basis of Height to Produce 100% Explosions	Evaluation on Basis of Height to Produce 100% Explosions for TNT-100	Average Evaluation on Basis of TNT-100	Total Trials During Testing	Remarks
4	1.6	25.0	2	13	4.9	1.9	1	6	8	3.1	26	1	4	11	100	92.5% E at 20 cm.
6	1.6	37.5	1	13	4.9	1.9	1	6	14	5.5	40	1	7	12	240	
6	1.6	10.0	3	13	8.1	3.2	3	10	55.30	9.9-11.8	82.5	5	12.5	14	180	
6	2.6	20.0	4	20	7.3	2.9	2	9	12	6.7	39	2	6	18	100	
6	2.6	15.0	5	20	10.0	3.9	4	12.5	20	7.6	56	4	10	20	320	
10	3.4	10.0	8	33	16.3	6.4	7	20	35	13.8	1.15	7	17.5	25.5	180	
8	3.1	2.5	7	27	15.9	6.3	6	20	30	11.8	.98	6	15	28	320	
8	3.1	5.0	6	27	16.7	6.6	8	20	35	13.8	1.15	7	17.5	31	160	
8	3.1	5.0	6	27	15.7	6.2	5	19.6	40	15.7	1.31	8	20	33	640	
12	3.9	2.5	9	33	28.0	11.1	12	35	50	18.7	1.64	9	25	35	420	
15	5.9	10.0	11	50	23.0	9.1	9	29	60	15.7	1.31	8	23	38	360	
15	5.9	10.0	11	50	25.0	9.9	10	31	75	20.5	2.46	11	37.5	46	220	
20	7.9	4.5	16	67	35.0	13.8	17	64	70	27.5	2.35	10	35	50	350	
15	5.9	15.0	10	50	26.0	10.2	11	32.5	75	20.5	2.46	11	37.5	52	310	
15	5.9	15.0	13	50	28.0	11.1	12	35	75	20.5	2.46	11	37.5	53	220	
15	5.9	5.0	13	50	33.0	13.0	14	41	72	25.5	2.46	11	37.5	54	420	
20	7.9	5.0	17	67	33.6	11.4	15	62	10	27.6	2.30	10	35	56	540	
20	7.9	10.0	17	67	20.0	11.8	13	37.5	90	35.4	2.95	12	65	58	180	
15	5.9	7.5	12	50	42.0	16.5	20	52.5	125	49.2	6.10	14	62.5	62	500	
25	9.9	7.5	18	81	34.8	13.7	16	43.5	93	35.4	2.95	12	65	63	460	
15	5.9	5.0	13	50	40.0	13.7	16	50	100	35.4	3.28	13	50	63.5	430	96.8% E at 125 cm.
20	7.9	15.0	13	67	41.0	16.1	19	51	125	49.2	6.10	16	62.5	64.5	420	
20	7.9	7.5	15	67	48.0	18.9	21	60	150	54.9	4.92	16	75	69	460	
30	11.8	15.0	22	100	60.0	23.6	25	75	125	59.2	6.10	15	65	70	480	
15	5.9	5.0	13	50	46.2	18.1	22	57.5	125	49.2	6.10	14	62.5	77	180	
30	11.8	25.0	21	100	44.0	17.1	21	55	125	49.2	6.10	14	62.5	83.5	220	95% E at 150 cm. Tests
30	11.8	10.0	23	100	78.0	30.7	30	97.5	175	69.2	5.76	18	87.5	85	460	
25	9.9	5.0	19	83	34.8	13.7	16	43.5	100	39.4	3.28	13	50	87	180	
30	11.8	6.7	24	100	62.2	24.5	26	78	125	69.2	6.10	14	62.5	88	420	
30	11.8	10.0	20	100	56.0	22.0	24	70	(145)	69.2	6.10	17	62.5	84.5	230	
30	11.8	15.0	22	100	70.0	27.6	28	87.5	175	69.2	5.76	18	87.5	77	220	
40	15.7	5.0	29	133	71.0	28.0	29	85	150	59.0	4.92	16	75	99	260	
30	11.8	3.1	25	100	30.0	31.5	31	100	200	78.8	6.54	19	100	100	700	
40	15.7	20.0	27	133	71.0	28.0	29	89	175	69.2	5.76	18	87.5	102	440	
40	15.7	15.0	28	133	70.0	27.6	28	87.5	125	69.2	6.10	16	62.5	113	160	
60	19.7	2.5	30	133	66.5	24.0	32	108	>300	>118	>9.84	20	>150	113	320	Average of 4 evaluations. 77.5% E at 337 cm. 95% E at 300 cm.
40	15.7	25.0	26	133	65.0	23.6	27	81	>300	>118	>9.84	21	>150	114	260	
40	15.7	5.0	29	133	118	46.4	33	147	337	132.5	11.0	22	160	170	230	
100	39.4	5.0	31	133	228	89.8	34	285	>337	>132.5	>11.0	23	>160	400	100	77.5% E at 337 cm.
150	59.0	10.0	32	500	350	137.7	35	437	>300	>118	>9.84	24	>150	600	120	Extrapolated. 37.5% E at 300 cm
337	132.5	10.0	33	11.5	>337	>132.5	36	>420	>337	>132.5	>11.0	25	>160	>600	30	10% E at 337 cm.
5	337	132.5	0	14	>337	>132.5	37	>420	>337	>132.5	>11.0	26	>160	>600	25	6% E at 337 cm.

TABLE

IMARY OF SIGNIFICANT DATA BY IMPACT DESIGN NO. 18

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Common Name of Explosive	2				4				6				8				E
	E	D	N	Ave. %E	E	D	N	Ave. %E	E	D	N	Ave. %E	E	D	N	Ave. %E	
Erythritol Tetra-nitrate	0	0	20	0	5	1	14	27.5	17	0	3	85	20	0	0	100	20
Tetracene					0	0	20	0	4	0	16	20	15	0	5	75	19
Nitromannite	0	0	40	0	15	0	25	37.5	27	0	13	67.5	39	0	1	97.5	39
PETN					0	0	40	0	3	0	37	7.5	9	0	31	22.5	30
α-HMX-RDX	0	0	20	0	2	3	15	17.5	3	6	11	30	6	7	7	47.5	10
Anhydroenneaheptitol Pentanitrate					0	0	20	0	0	1	19	2.5	0	3	17	7.5	2

Common Name of Explosive	6				8				10				12				E
	E	D	N	Ave. %E	E	D	N	Ave. %E	E	D	N	Ave. %E	E	D	N	Ave. %E	
50/50 PETN-Picronite	0	0	20	0	1	0	19	5	0	2	15	5	4	5	11	32.5	8
β-HMX	0	0	40	0	2	3	36	6.3	7	1	32	18.8	5	2	33	15	17
RDX	0	0	40	0	2	0	38	5	5	0	55	8.3	10	3	27	28.6	20
NELO	0	0	40	0	0	2	38	.5	0	6	34	7.5					4
DINA	0	0	40	0	0	1	39	1.3	1	2	37	5					1

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10					12				14				15				16				
E	D	N	Ave.	SE	E	D	N	Ave.	SE	E	D	N	Ave.	SE	E	D	N	Ave.	SE	E	
			0	100																	
5	10	0	1	15	20	0	0	100													
10	10	0	1	17.5	38	0	2	95	20	0	0	100									
20	10	0	30	50	34	0	6	85	38	0	2	95					39	0	1	97.5	20
10	10	0	4	65	11	7	2	72.5	11	2	7	72.5					15	4	1	85	17
3	10	0	5	13	22.5								6	5	9	42.5					10

				15				20				25				30				35				
				E	D	N	Ave. SE	E	D	N	Ave. SE	E	D	N	Ave. SE	E	D	N	Ave. SE	E	D	N	Ave. SE	E
5	11	12.5		8	6	6	55	11	4	5	65	15	3	2	82.5	19	1	0	97.5	20	0	0	100	
2	13	15		17	3	20	46.3	29	9	2	83.8	34	4	2	90	40	0	0	100					10
3	27	25.8		20	9	31	40.8	50	3	3	85.8	54	3	3	92.5	55	5	0	95.8					20
				4	13	23	26.3	8	3	23	31.3	12	21	7	56.3	21	14	5	70	26	14	0	82.5	20
				1	5	34	8.8	9	8	23	32.5	17	8	15	52.5	17	11	12	56.3	19	11	10	61.3	27

TABLE II

SUMMARY OF DESIGN 12 DATA FOR CLASS I EXPLOSIVES
DROP-HEIGHT OF 2.5 KILOGRAM HAMMER IN CM.

2

8	10	12	14	16	16
D N Ave. SE	E D N Ave. SE	E D N Ave. SE	E D N Ave. SE	E D N Ave. SE	E D N
0 0 100	20 0 0 100				
0 5 75	19 0 1 95	20 0 0 100			
0 1 97.5	39 0 1 97.5	39 0 2 95	20 0 0 100		
0 31 22.5	30 0 30 50	34 0 6 85	38 0 2 95		39 0 1
7 7 47.5	10 6 4 65	11 7 2 72.5	11 2 7 72.5		15 4 1
3 17 7.5	2 5 13 22.5			6 5 9 42.5	

12	15	20	25	30	35
D N Ave. SE	E D N Ave. SE	E D N Ave. SE	E D N Ave. SE	E D N Ave. SE	E D N
5 11 32.5	8 6 6 55	11 4 5 65	15 3 2 82.5	19 1 0 97.5	20 0 0
2 33 15	17 3 20 46.3	29 9 2 83.8	34 4 2 90	40 0 0 100	
3 27 28.8	20 9 31 40.8	50 3 3 85.8	54 3 3 92.5	55 5 0 95.8	
	4 13 23 26.3	9 9 23 31.3	12 21 7 56.3	21 14 5 70	26 14 0
	1 5 34 8.8	9 8 23 32.5	17 8 15 52.5	17 11 12 56.3	19 11 10

TABLE II

SUMMARY OF DESIGN 12 DATA FOR CLASS I EXPLOSIVES
DROP-HEIGHT OF 2.5 KILOGRAM HAMMER IN CM.

	16				20				25				30				35			
ve. SE	E	D	N	Ave. SE	E	D	N	Ave. SE	E	D	N	Ave. SE	E	D	N	Ave. SE	E	D	N	Ave. SE
	39	0	1	97.5	20	0	0	100												
	15	4	1	85	17	3	0	92.5												
2.5					10	7	3	67.5	14	6	0	85	17	3	0	92.5	20	0	0	100

	35				40				45				50				
Ave. SE	E	D	N	Ave. SE	E	D	N	Ave. SE	E	D	N	Ave. SE	E	D	N	Ave. SE	
97.5	20	0	0	100													
100					10	0	0	100									
95.8					20	0	0	100									
70	26	14	0	82.5	20	0	0	100					20	0	0	100	
56.3	19	11	10	61.3	27	7	6	76.3	33	6	1	90	20	0	0	100	

2

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Common Name of Explosive	8				10				15				20				25			
	E	D	N	Ave. %E	E	D	N	Ave. %E	E	D	N	Ave. %E	E	D	N	Ave. %E	E	D	N	Ave. %E
50/50 P-I-Pivonite	0	0	20	0	0	1	19	2.5	2	2	16	15	6	4	10	40	8	4	8	50
50/50 EDNA-Pivonite	0	0	40	0	0	1	39	1.3	0	5	35	6.3	1	10	29	15				
Baronal					0	0	20	0	1	1	18	7.5	3	5	12	27.5	8	2	10	45
EDNA					0	0	40	0	1	2	37	5	1	3	36	6.3	8	9	23	31.

Common Name of Explosive	10				15				20				25				30			
	E	D	N	Ave. %E	E	D	N	Ave. %E	E	D	N	Ave. %E	E	D	N	Ave. %E	E	D	N	Ave. %E
Pivonite	0	0	40	0	6	9	25	26.3	14	11	15	48.8					23	9	8	68.
Torpex I	0	0	20	0	0	4	16	10	2	4	14	20					9	5	6	57.
Tetryl	0	0	40	0	0	5	35	6.3	0	8	32	10	3	7	30	16.3	9	16	15	42.
Emmet	0	0	40	0	2	0	38	5	1	1	35	3.8	4	5	31	16.3	7	7	26	26.
NH ₄ ClO ₄									0	0	20	0	1	2	17	10	6	5	7	52.
50/50 Fentolite	0	0	40	0	0	8	32	10	3	12	45	15	5	14	21	30	18	11	31	39.

Common Name of Explosive	10				15				20				30				40			
	E	D	N	Ave. %E	E	D	N	Ave. %E	E	D	N	Ave. %E	E	D	N	Ave. %E	E	D	N	Ave. %E
Composite Propellant					0	0	20	0	0	1	19	2.5	5	3	12	32.5	8	7	5	57.
Sizonite	0	0	40	0	0	1	39	1.3	3	6	31	15	4	13	23	26.3	13	11	16	46.

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30	35	40	45	50	60
E D N Ave. SE	E D N Ave. SE	E D N Ave. SE	E D N Ave. SE	E D N Ave. SE	E D N Ave. SE
8 4 8 50	13 4 3 75	13 3 4 72.5	14 5 1 82.5	17 3 0 92.5	19 2 0 95
	12 15 13 48.8		16 15 9 58.8	18 18 4 67.5	50 10 0 95
8 2 10 45	16 2 2 65	18 1 1 92.5	16 1 3 82.5	26 0 14 65	19 1 0 96
8 9 23 31.3	16 10 14 52.5	16 15 5 58.8	21 12 7 67.5	24 11 5 73.8	30 7 3 83.8
					39 1 0 96

30	35	40	45	50	60	70
E D N Ave. SE	E D N Ave. SE	E D N Ave. SE	E D N Ave. SE	E D N Ave. SE	E D N Ave. SE	E D N Ave. SE
23 9 8 68.8		22 11 7 68.8		28 12 0 85	33 3 4 86.3	
9 5 6 57.5		14 4 2 80		11 7 2 72.5	18 1 1 92.5	
9 16 15 42.5	22 9 9 66.3	23 11 6 71.3	25 13 2 78.8	31 9 0 88.8	33 7 0 91.3	38 2 0 95
7 7 26 26.3		16 8 16 50		24 6 10 67.5	31 4 5 83.8	36 1 3 95
6 5 7 52.5		11 4 5 65		15 2 3 80	16 3 1 87.5	18 2 0 95
18 11 31 39.2	18 10 12 57.5	28 21 11 64.2	24 14 2 77.5	40 19 1 82.5	55 5 0 95.1	20 0 0 1

40	50	60	70	75	80	90
E D N Ave. SE	E D N Ave. SE	E D N Ave. SE	E D N Ave. SE	E D N Ave. SE	E D N Ave. SE	E D N Ave. SE
8 7 5 57.5	9 7 4 57.5	11 3 6 62.5		15 4 1 85		18 1 1
13 11 16 46.3	15 13 12 53.8	18 14 8 62.5	22 12 6 70		21 13 6 68.8	29 8 3

TABLE III
SUMMARY OF DESIGN 12 DATA FOR CLASS II EXPLOSIVES
DROP-HEIGHT OF 2.5 KILOGRAM HAMMER IN CM.

20	25	30	35	40	45	
D N Ave. SE	E D N Ave. SE	E D N Ave. SE	E D N Ave. SE	E D N Ave. SE	E D N Ave. SE	E D
4 10 40	8 4 8 50	13 4 3 75	13 3 4 72.5	14 5 1 82.5		17 3
10 29 15		12 15 13 25.2		16 15 9 58.5		18 18
5 12 27.5	8 2 10 45	16 2 2 25	18 1 1 92.5	16 1 3 82.5		26 0
3 36 6.3	3 9 23 31.3	16 10 14 52.5	16 15 9 58.2	21 12 7 67.5	24 11 5 73.8	30 7

25	30	35	40	45	50	
D N Ave. SE	E D N Ave. SE	E D N Ave. SE	E D N Ave. SE	E D N Ave. SE	E D N Ave. SE	E D
	23 9 8 68.8		22 11 7 65.5		26 12 0 65	33 3
	9 5 6 57.5		14 4 2 60		11 7 2 72.5	18 1
7 30 16.3	9 16 15 42.5	22 9 9 66.3	23 11 6 71.3	25 13 2 75.6	31 9 0 88.8	33 7
5 31 16.3	7 7 26 26.3		16 8 16 50		24 6 10 67.5	31 4
2 17 10	8 5 7 52.5		11 4 5 65		15 2 3 80	16 3
14 21 30	18 11 31 39.2	18 10 12 57.5	28 21 11 64.2	24 14 2 77.5	40 19 1 82.5	55 5

30	40	50	60	70	75	
D N Ave. SE	E D N Ave. SE	E D N Ave. SE	E D N Ave. SE	E D N Ave. SE	E D N Ave. SE	E D
3 12 32.5	8 7 5 57.5	9 7 4 57.5	11 3 6 62.5		15 4 1 85	
13 23 26.3	13 11 16 46.3	15 13 12 53.2	16 14 8 62.5	22 12 6 70		21 13

TABLE III

SUMMARY OF DESIGN 12 DATA FOR CLASS II EXPLOSIVES
DROP-HEIGHT OF 2.5 KILOGRAM HAMMER IN CM.

45	50	60	70	75		
E D N Ave. SE	E D N Ave. SE	E D N Ave. SE	E D N Ave. SE	E D N Ave. SE		
	17 3 0 92.5	19 2 0 95		20 0 0 100		
	18 18 4 67.5	50 10 0 91.7	40 3 0 100			
	26 0 14 65	19 1 0 97.5		20 0 0 100		
24 11 5 73.6	30 7 3 83.8	39 1 0 98.8		20 0 0 100		

50	60	70	75	80	90	100
E D N Ave. SE	E D N Ave. SE	E D N Ave. SE	E D N Ave. SE	E D N Ave. SE	E D N Ave. SE	E D N Ave. SE
26 12 0 85	33 3 4 86.3		20 0 0 100			10 0 0 100
11 7 2 72.5	18 1 1 92.5		18 2 0 95		20 0 0 100	
31 9 0 88.8	33 7 0 91.3	36 2 0 97.5			20 0 0 100	
24 6 10 67.5	31 4 5 83.8	36 1 3 90.8	18 2 0 95			20 0 0 100
15 2 3 80	16 3 1 87.5	18 2 0 95		19 1 0 97.5		20 0 0 100
40 19 1 82.5	55 5 0 95.1	20 0 0 100				20 0 0 100

75	80	90	100	125	150	
E D N Ave. SE	E D N Ave. SE	E D N Ave. SE	E D N Ave. SE	E D N Ave. SE	E D N Ave. SE	
15 4 1 85		16 1 1 92.5	19 1 0 97.5	20 0 0 100		
	21 13 6 68.6	29 8 3 82.5	27 10 3 60	17 3 0 92.5	20 0 0 100	

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Common Name of Explosive	10				15				20				30				40			
	E	D	N	Ave. SE	E	D	N	Ave. SE	E	D	N	Ave. SE	E	D	N	Ave. SE	E	D	N	Ave. SE
Minol-2	0	0	20	0	1	0	19	5	1	0	19	5	4	1	15	22.5	11	1	8	57.5
Picric Acid	0	0	40	0	2	3	35	8.8	11	11	38	27.5	13	17	30	35.8	17	21	22	45.8
50/50 Ednatol	0	0	40	0	0	2	38	2.5	0	1	39	1.3	6	12	22	30	10	10	20	37.5
Trinitronaphthalene									0	0	20	0	0	1	19	2.5	3	2	15	20
75/25 Tetrytol	0	0	40	0	0	4	36	5	6	6	26	25	18	4	18	50	21	4	15	57.5
Composition B					0	0	40	0	0	4	56	3.3	4	16	40	20	4	20	36	23.3

Common Name of Explosive	15				20				30				40				50			
	E	D	N	Ave. SE	E	D	N	Ave. SE	E	D	N	Ave. SE	E	D	N	Ave. SE	E	D	N	Ave. SE
Tetranitronaphthalene	0	0	20	0	0	1	19	2.5	0	3	17	7.5	1	3	16	12.5	8	4	8	50
Trinitrobenzene	0	0	20	0	0	1	19	2.5	6	3	11	37.5	5	2	13	30	10	0	10	50
50/50 Amatol	0	0	20	0	0	3	17	7.5	3	6	11	30	3	5	12	27.5	6	3	11	37.5
British Composition A	0	0	40	0	0	1	39	1.3	0	8	32	10	8	9	23	31.3	11	19	30	34.2

Common Name of Explosive	10				15				20				30				40			
	E	D	N	Ave. SE	E	D	N	Ave. SE	E	D	N	Ave. SE	E	D	N	Ave. SE	E	D	N	Ave. SE
MNO	0	0	40	0	0	1	39	1.3	0	1	39	1.3	4	5	31	16.3	6	10	24	27.5

Common Name of Explosive	15				20				25				30				40			
	E	D	N	Ave. SE	E	D	N	Ave. SE	E	D	N	Ave. SE	E	D	N	Ave. SE	E	D	N	Ave. SE
TNT	0	0	40	0	0	1	39	1.3	0	4	36	5	2	7	51	9.2	3	12	65	11.3

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40	50	60	70	75	80	90
E D N Ave. SE	E D N Ave. SE	E D N Ave. SE	E D N Ave. SE	E D N Ave. SE	E D N Ave. SE	E D N Ave. SE
1 8 57.5	11 1 8 57.5			13 4 3 75		
21 22 45.8	24 21 15 57.5	44 14 2 85	51 7 2 90.8		19 1 0 97.5	
10 20 37.5	8 16 16 40	11 12 17 42.5	17 11 12 56.3		20 12 8 65	33 5 2 88
2 15 20	2 5 13 22.5	5 8 7 45		11 5 4 67.5		
4 15 57.5	23 7 10 66.3	29 4 7 77.5	29 8 3 82.5		34 6 0 92.5	18 2 0 95
20 36 23.3	18 20 42 35	20 17 23 47.5	27 19 14 60.8		37 18 5 76.7	50 9 1 90

50	60	70	75	80	90	100
E D N Ave. SE	E D N Ave. SE	E D N Ave. SE	E D N Ave. SE	E D N Ave. SE	E D N Ave. SE	E D N Ave. SE
3 4 8 50	5 3 12 32.5		13 1 6 67.5			15 4 1 85
0 0 10 50	8 3 9 47.5	11 0 9 55		11 1 8 57.5	15 4 1 85	15 3 2 82
6 3 11 37.5			6 8 6 50			9 7 4 62
1 19 30 34.2			20 20 20 50			34 18 8 71

40	50	60	70	80	90	100
E D N Ave. SE	E D N Ave. SE	E D N Ave. SE	E D N Ave. SE	E D N Ave. SE	E D N Ave. SE	E D N Ave. SE
6 10 24 27.5	11 8 21 37.5	12 9 19 41.3	14 9 17 46.3	5 6 9 40	9 6 5 60	11 4 5 65

40	50	75	100	125	150	175
E D N Ave. SE	E D N Ave. SE	E D N Ave. SE	E D N Ave. SE	E D N Ave. SE	E D N Ave. SE	E D N Ave. SE
3 12 65 11.3	15 24 81 22.5	35 26 39 48	56 19 25 65.5	41 12 7 78.4	45 9 6 82.5	59 1 0 99

TABLE IV
SUMMARY OF DESIGN 12 DATA FOR CLASS III EXPLOSIVES
DROP-HEIGHT OF 2.5 KILOGRAM HAMMER IN CM

2

40				50				60				70				75				80			
E	D	N	Ave. SE	E	D	N	Ave. SE	E	D	N	Ave. SE	E	D	N	Ave. SE	E	D	N	Ave. SE	E	D	N	Ave. SE
11	1	8	57.5	11	1	8	57.5									13	4	3	75				
17	21	22	45.8	24	21	15	57.5	44	14	2	65	51	7	2	50.8					13	1	0	
10	10	20	37.5	8	16	16	40	11	12	17	42.5	17	11	12	56.3					20	12	8	
3	2	15	20	2	5	13	22.5	5	8	7	45					11	5	4	67.5				
21	4	15	57.5	23	7	10	66.3	29	4	7	77.5	29	8	3	82.5					34	6	0	
4	20	36	23.3	18	20	42	35	20	17	23	47.5	27	19	14	60.8					37	18	5	

50				60				70				75				80				90			
E	D	N	Ave. SE	E	D	N	Ave. SE	E	D	N	Ave. SE	E	D	N	Ave. SE	E	D	N	Ave. SE	E	D	N	Ave. SE
8	4	8	50	5	3	12	32.5					13	1	6	67.5								
10	0	10	50	8	3	9	47.5	11	0	9	55					11	1	8	57.5	15	4	1	
6	3	11	37.5									6	8	6	50								
11	19	30	34.2									20	20	20	50								

40				50				60				70				80				90			
E	D	N	Ave. SE	E	D	N	Ave. SE	E	D	N	Ave. SE	E	D	N	Ave. SE	E	D	N	Ave. SE	E	D	N	Ave. SE
6	10	24	27.5	11	8	21	37.5	12	9	19	41.3	14	9	17	46.3	5	6	9	40	9	6	5	

40				50				75				100				125				150			
E	D	N	Ave. SE	E	D	N	Ave. SE	E	D	N	Ave. SE	E	D	N	Ave. SE	E	D	N	Ave. SE	E	D	N	Ave. SE
3	12	65	11.3	15	24	81	22.5	35	26	39	48	36	19	25	64.5	41	12	7	78.4	45	9	6	

TABLE IV
SUMMARY OF DESIGN 12 DATA FOR CLASS III EXPLOSIVES
DROP-HEIGHT OF 2.5 KILOGRAM BANNER IN Cm

1

	80				90				100				125					
	E	D	N	Ave. SE	E	D	N	Ave. SE	E	D	N	Ave. SE	E	D	N	Ave. SE		
5									17	2	1	90	20	0	0	100		
	13	1	0	97.5					18	1	1	92.5	20	0	0	100		
	20	12	8	65	33	5	2	88.8	32	7	1	88.8	39	1	0	98.8		
7.5									13	4	3	75	20	0	0	100		
	34	6	0	92.5	18	2	0	95	19	1	0	97.5	20	0	0	100		
	37	18	5	76.7	50	9	1	90.8	56	4	0	96.7	20	0	0	100		

	90				100				125				150				175			
	E	D	N	Ave. SE	E	D	N	Ave. SE	E	D	N	Ave. SE	E	D	N	Ave. SE	E	D	N	Ave. SE
					15	4	1	85	14	4	2	80	20	0	0	100				
7.5	15	4	1	85	15	3	2	82.5	13	2	5	70	9	1	0	95				
					9	7	4	62.5	15	3	2	62.5	19	1	0	97.5	20	0	0	100
					34	18	8	71.6	33	4	3	87.5	37	3	0	96.3	20	0	0	100

	90				100				110				125				150				175			
	E	D	N	Ave. SE	E	D	N	Ave. SE	E	D	N	Ave. SE	E	D	N	Ave. SE	E	D	N	Ave. SE	E	D	N	Ave. SE
40	9	6	5	60	11	4	5	65	14	4	2	80	18	2	0	95	19	1	0	97.5	20	0	0	100

	150				175				200							
	E	D	N	Ave. SE	E	D	N	Ave. SE	E	D	N	Ave. SE				
78.4	45	9	6	62.5	59	1	0	99.2	20	0	0	100				

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Common Name of Explosive	30				40				50				60			
	E	D	N	Ave. %E	E	D	N	Ave. %E	E	D	N	Ave. %E	E	D	N	A
Diammonium Ednate	0	0	20	0	5	2	13	30	5	5	10	37.5	8	5	7	5

Common Name of Explosive	25				30				40				50			
	E	D	N	Ave. %E	E	D	N	Ave. %E	E	D	N	Ave. %E	E	D	N	A
Ammonium Picrate	0	0	40	0	0	1	39	1.3	1	5	34	8.8	9	7	45	1

Common Name of Explosive	30				40				50				75			
	E	D	N	Ave. %E	E	D	N	Ave. %E	E	D	N	Ave. %E	E	D	N	A
Potassium Chlorate	0	0	20	0	1	1	18	7.5	1	4	15	17.5	8	6	6	!
Ammonium Nitrate	0	0	20	0	0	0	20	0	0	0	20	0	0	0	20	
Potassium Perchlorate	-	-	-	-	-	-	-	-	0	0	20	0	-	-	-	
Nitroguanidine																
Guanidine Nitrate																

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	60				70				80				90				100			
Ave. N SE	E	D	N	Ave. SE	E	D	N	Ave. SE	E	D	N	Ave. SE	E	D	N	Ave. SE	E	D	N	Ave. SE
0 37.5	8	5	7	52.5	9	4	7	55	11	5	4	67.5	12	3	5	67.5	13	4	3	75

	50				75				100				125				150			
Ave. N SE	E	D	N	Ave. SE	E	D	N	Ave. SE	E	D	N	Ave. SE	E	D	N	Ave. SE	E	D	N	Ave. SE
A 8.8	8	7	45	19.2	26	13	21	54.2	30	14	16	61.7	38	16	6	76.7	42	15	5	80.8

	75				100				125				150				175			
Ave. N SE	E	D	N	Ave. SE	E	D	N	Ave. SE	E	D	N	Ave. SE	E	D	N	Ave. SE	E	D	N	Ave. SE
15 17.5	8	6	5	55	6	5	9	42.5	11	4	5	65	12	1	7	52.5	11	4	5	65
20 0	0	0	20	0	1	1	18	7.5	-	-	-	-	7	0	13	35	-	-	-	-
20 0	-	-	-	-	0	1	19	2.5	-	-	-	-	2	0	18	10	-	-	-	-
					0	0	10	0	-	-	-	-	-	-	-	-	-	-	-	-
					0	0	10	0	-	-	-	-	-	-	-	-	-	-	-	-

TABLE V
SUMMARY OF DESIGN 12 DATA FOR CLASS IV EXPLOSIVES
DROP-HEIGHT OF 2.5 KILOGRAM HAMMER IN Cm.

50	60				70				80				90				
D N Ave. SE	E	D	N	Ave. SE	E	D	N	Ave. SE	E	D	N	Ave. SE	E	D	N	Ave. SE	E
5 10 37.5	8	5	7	52.5	9	4	7	55	11	5	4	67.5	12	3	5	67.5	13

40	50				75				100				125				
D N Ave. SE	E	D	N	Ave. SE	E	D	N	Ave. SE	E	D	N	Ave. SE	E	D	N	Ave. SE	E
5 34 8.8	8	7	45	19.2	26	13	21	54.2	30	14	16	61.7	38	16	6	76.7	42

50	75				100				125				150				
D N Ave. SE	E	D	N	Ave. SE	E	D	N	Ave. SE	E	D	N	Ave. SE	E	D	N	Ave. SE	E
4 15 17.5	8	6	6	55	6	5	9	42.5	11	4	5	65	12	1	7	62.5	11
0 20 0	0	0	20	0	1	1	18	7.5	-	-	-	-	7	0	13	35	-
0 20 0	-	-	-	-	0	1	19	2.5	-	-	-	-	2	0	18	10	-
					0	0	10	0	-	-	-	-	-	-	-	-	-
					0	0	10	0	-	-	-	-	-	-	-	-	-

TABLE V

SUMMARY OF DESIGN 12 DATA FOR CLASS IV EXPLOSIVES
DROP-HEIGHT OF 2.5 KILOGRAM HAMMER IN CM.

0	100				125				150				200				300			
Ave. N SE	E	D	N	Ave. SE	E	D	N	Ave. SE	E	D	N	Ave. SE	E	D	N	Ave. SE	E	D	N	Ave. SE
5 67.5	13	4	3	75	12	3	5	67.5	10	5	4	65	6	3	1	75	9	1	0	95

125	150				175				200				225				300			
Ave. N SE	E	D	N	Ave. SE	E	D	N	Ave. SE	E	D	N	Ave. SE	E	D	N	Ave. SE	E	D	N	Ave. SE
6 76.7	42	15	5	80.8	35	4	1	92.	18	1	1	92.5	17	2	1	90	19	1	0	97.5

150	175				200				250				300				337			
Ave. N SE	E	D	N	Ave. SE	E	D	N	Ave. SE	E	D	N	Ave. SE	E	D	N	Ave. SE	E	D	N	Ave. SE
7 62.5	11	4	5	65	13	1	6	67.5	17	1	2	87.5	17	1	2	87.5	10	0	0	100
13 35	-	-	-	-	7	4	9	45	-	-	-	-	11	3	6	62.5	14	3	3	77.5
18 10	-	-	-	-	6	1	13	32.5	3	5	12	27.5	7	1	12	37.5				
- - -	-	-	-	-	0	1	9	5	-	-	-	-	-	-	-	-	1	0	9	10
- - -	-	-	-	-	0	0	10	0	-	-	-	-	-	-	-	-	0	0	5	0

PLCSIVES

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Common Name of Explosive	10			15			20			30			50											
	E	P	Ave.	E	P	Ave.	E	P	Ave.	E	P	Ave.	E	P	Ave.									
50/50 Pentolite	0	0	20	0	0	0	5	7	24	16	12	15	22	12	6	70	22	15	5	71.8				
Trispar-2	-	-	-	0	0	0	0	0	0	1	39	1.5	2	4	33	12.5	3	5	31	16.2	16	4	20	45
Minol-0	-	-	-	-	-	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
BMX	0	0	0	0	1	34	1.5	0	2	36	2.5	5	7	30	16.2	7	6	24	41.7	15	4	23	37.5	
Composition B	-	-	-	0	0	0	0	0	0	0	3	3	3.7	1	1	30	18.7	6	13	41	31.4	-	-	-

Common Name of Explosive	50			75			100			125			150											
	E	P	Ave.	E	P	Ave.	E	P	Ave.	E	P	Ave.	E	P	Ave.									
B.H.S.	0	0	20	0	1	34	1.5	5	6	31	15	7	10	23	30	18	10	16	47.5	20	10	8	67.5	
Trispar-2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
BMX	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Composition B	15	11	16	46.2	19	11	10	61.2	24	11	5	73.7	25	5	0	93.7	20	0	0	100	20	0	0	100

Common Name of Explosive	50			75			100			125			150			275		
	E	P	Ave.	E	P	Ave.	E	P	Ave.	E	P	Ave.	E	P	Ave.	E	P	Ave.
50/50 Pentolite	-	-	-	38	2	0 97.5	20	0	0 100									
Trispar-2	-	-	-	26	11	21 55.8	32	5	0 86.2	34	5	11 93.7	20	0	0 100			
Minol-2	-	-	-	24	5	20 68.7	35	2	3 90	34	1	1 94.2	20	0	0 100			
BMX	-	-	-	17	10	23 55	26	6	6 77.5	34	6	0 92.5	37	3	0 92.5	20	0	0 100
Composition B	15	11	16 46.2	19	11	10 61.2	24	11	5 73.7	25	5	0 93.7	20	0	0 100			

Common Name of Explosive	175			200			250			300			350													
	E	P	Ave.	E	P	Ave.	E	P	Ave.	E	P	Ave.	E	P	Ave.											
B.M.B.	33	4	3	87.5	18	2	0	95	19	1	0	97.5	20	0	0	100	-	-	-	-	-	-	-	-	-	-
Trispar-2	24	12	2	75	32	6	2	86.5	17	1	2	87.5	19	1	0	97.5	19	1	0	97.5	-	-	-	-	-	-

TABLE VI

SUMMARY OF RECENT DATA WITH DESIGN 12.
MATERIALS SUBMITTED THROUGH 16 ON 50 MESH
BROOK-BENTON OF 2.5 KILOGRAM BARREL IN CM.

TABLE VII
SUMMARY OF GRAPHICAL (PROBABILITY GRAPHS) 50% EXPLOSION DROP-HEIGHTS FOR DESIGN NO. 12

Common Name of Explosive or Mixture	Chemical Name of Explosive or Composition of Explosive Mixture	On Basis of Average % Explosions	
		50% Explosion Drop-Height (cm.)	Evaluation on Basis of TNT = 100 units
ETN	Erythritol Tetranitrate	4.6	I
Nitromannite	Mannitol Hexanitrate	4.7	I
Tetrafene	1-Guanyl-4-Nitrosaminoquanyl-tetrasene	7.2	I
α-HMX-RDX Mixture	-----	9.1	I
PEIN	Pentaerythritol Tetranitrate	9.5	I
β-HMX	Cyclotetramethylene Tetranitramine	15	I
RDX	Cyclotrimethylene Trinitramine	15	I
-----	Anhydroenneheptitol Pentanitrate	15	I
PEIN-Fivonite, 50/50	-----	16.6	I
NENO	Dinitroxyethylnitroxamide	23	I
Fivonite	Tetramethylcyclopentanone Tetranitrate	23	II
RDX-Fivonite, 50/50	-----	24	II
DEVA	Diethanolnitramine	25	I
Baronal	50 parts Ba(NO ₃) ₂ , 35 parts TNT, 15 parts aluminum powder	25.6	II
EDNA-Fivonite, 50/50	-----	30	II
Torpex-I, Ground	45 parts RDX, 37 parts TNT, 18 parts aluminum powder	30	II
EDNA	Ethylenedinitramine	31.5	II
Tetryl	2,4,6-Trinitrophenylmethylnitramine	32	II
Pentolite	50 parts PEIN, 50 parts TNT	32	II
Ammonium Perchlorate	Same	36	II
Picric Acid	2,4,6-Trinitrophenol	36	III
Tetrytol	75 parts Tetryl, 25 parts TNT	36	III
Emmet	Ethyltrimethylolmethane Trinitrate	38	II

TABLE VII (cont'd)
SUMMARY OF GRAPHICAL (PROBABILITY GRAPHS) 50% EXPLOSION DROP-HEIGHTS FOR DESIGN NO. 12

Common Name of Explosive or Mixture	Chemical Name of Explosive or Composition of Explosive Mixture	On Basis of Average % Explosions	
		50% Explosion Drop-Height (cm)	Evaluation on Basis of TNT - Class 100 units
Composite Propellant	5 parts Buramine 65%, 1.5 parts Santicizer No. 8	43	II 57
Mino'-2, Ground	90 parts ammonium picrate (45%), KNO ₃ (55%) 40 parts NH ₄ NO ₃ , 40 parts TNT, 20 parts aluminum powder	45	III 60
Sisonite	Tetramethyloctocyclohexone Tetranitrate	47.5	II 63
Ednatol	50 parts EDNA, 50 parts TNT	55	III 73
Composition B	59.5 parts RDX, 39.5 parts TNT, 1 part wax	55	III 73
TNB	2, 4, 6-Trinitrobenzene	59	III 79
-----	1, 3, 5, 8-Tetranitronaphthalene	59	III 79
Amatol, 50/50	50 parts NH ₄ NO ₃ , 50 parts TNT	61	III 81
British Composition A	90 parts RDX, 10 parts wax	63	III 84
-----	1, 3, 6-Trinitronaphthalene	65	III 87
Diammonium Ednate	N-N'-diammonium ethylene dinitramine	66	IV 88
MNO	N,N'-dimethyl-N,N'-dinitro-oxamide	66.5	III 89
TNT	2, 4, 6-Trinitrotoluene	75	III 100
Explosive D	Ammonium Picrate	87	IV 116
Potassium Chlorate	Same	113	IV 151
Ammonium Nitrate	Same	228	IV 304
Potassium Perchlorate	Same	375	IV 500
Nitroguanidine	Same	>631	IV >100
Guanidine Nitrate	Same	>631	IV >100

TABLE VII (cont'd)
SUMMARY OF GRAPHICAL (PROBABILITY GRAPH) 50% EXPLORATION DROP-HEIGHTS FOR DESIGN NO. 12

Common Name of Explosive or Mixture	On Basis of Doubtful Explosions counted as Failures 50% Exploration		Class	Evaluation on Basis of TNT *	
	Drop-height (in.)	100 units		Drop-height (in.)	100 units
ETN	4.6	5	I		
Nitromannite	4.7	5	I		
Tetracene	7.2	8	I		
PETN	9.5	10	I		
4-HMX-RDX Mixture	10.6	13	I		
β-HMX	16.5	18	I		
RDX	16.5	18	I		
PETN-Fivonite, 50/50	17	18	I		
Anhydronneheptitol Pentanitrate	19	21	I		
NENO	29	31	I		
Fivonite	29	31	II		
RDX-Fivonite, 50/50	29	31	II		
Baronal	29	31	II		
DINA	29	31	II		
Torpex-I, Ground	31.6	34	I		
EDNA	35	37	II		
Tetryl	38	40	II		
Ammonium Perchlorate	40	43	II		
Pestolite	40	43	II		
EDNA-Fivonite	42	45	II		
Tetrytol	42	45	III		
Emmet	44	47	II		
Picric Acid	48	51	III		

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TABLE IV (cont'd)
SUMMARY OF GRAPHICAL (PROBABILITY GRAPHS) 50% EXPLOSION DROP-HEIGHTS FOR DESIGN NO. 12

Common Name of Explosive or Mixture	On Basis of Doubtful Explosions Counted as Failures		Class	Drop-Height (cm)
	50% Explosion	Evaluation on Basis of TNT *		
				100 units
Composite Propellant				
Minol-2	48		II	51
TNB	50		III	53
Ednatol	66		III	70
Composition B	68		III	72
Sisonite	68		III	72
Tetranitronaphthalene	68		II	72
Amatol, 50/50	72		III	77
British Composition A	79		III	84
Trinitronaphthalene	79		III	84
Diammonium Ednate	79		IV	84
MNO	79		III	84
TNT	94		III	100
Explosive D	106		IV	113
Potassium Chlorate	139		IV	148
Ammonium Nitrate	250		IV	266
Potassium Perchlorate	328		IV	349
Nitroguanidine	>631		IV	>100
Guanidine Nitrate	>631		IV	>100

TABLE VIII
DIRECT COMPARISON OF EVALUATED 50% EXPLOSION DROP-HEIGHTS

Name of Explosive	Evaluation of 50% Explosion Drop-Height on Basis of average % Explosions and the 50% Explosion Height of TNT taken as 100 units.	Evaluation of 50% Explosion Drop-Height on Basis of % Explosions with Doubtful Explosions counted as Failures and the 50% Explosion Height of TNT taken as 100 units.
Erithritol Tetranitrate	6	5
Nitromannite	6	5
Tetrazene	10	8
A-HMX-KDX Mixture	12	13
PETN	13	10
P-HMX	20	18
RDX	20	18
Anhydroenneheptitol P-nitrate	20	21
PETN-Fivonite, 50/50	22	18
NENO	31	31
Fivonite	31	31
RDX-Fivonite, 50/50	32	34
DNA	33	31
Baronal	34	45
EDNA-Fivonite, 50/50	40	37
Terpen-1	40	40
EDNA	42	43
Tetryl	43	43
Pentolite	43	43
Ammonium Perchlorate	48	51
Picric Acid	48	45
Tetrytol, 75/25	48	45
Emmet	51	47

TABLE VIII (cont'd)

DIRECT COMPARISON OF EVALUATED 50% EXPLOSION DROP-HEIGHTS

Name of Explosive	Evaluation of 50% Explosion Drop-Height on Basis of Average % Explosions and the 50% Explosion Height of TNT taken as 100 units	Evaluation of 50% Explosion Drop-Height on Basis of % Explosions with Doubtful Explosions counted as Failures and the 50% Explosion Height of TNT taken as 100 units
Composite Propellant	57	51
Minot-2	66	53
Sizonite	63	72
Ednatol	73	72
Composition B	73	72
Trinitrobenzene	74	70
Tetranitronaphthalene	79	77
Amatol, 50, 50	81	84
British Composition A	84	84
Trinitronaphthalene	87	84
Diammonium Ednate	88	84
MNO	89	84
TNT	100	100
Ammonium Picrate	116	113
Potassium Chlorate	151	148
Ammonium Nitrate	304	266
Potassium Perchlorate	500	349
Nitroguanidine	>100	>100
Guanidine Nitrate	>100	>100

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TABLE 12
SUMMARY OF GRAPHICAL 10% EXPLOSION HEIGHTS FOR COARSE MATERIALS
BY DESIGN NO. 12

Common Name of Explosive	On Basis of Actual Explosions 10% Explosion Drop Height (Cm.)			Common Name of Explosive	On Basis of Double Explosions Considered as Failures 10% Explosion Drop Height (Cm.)		
	Actual	Standard			Actual	Standard	
Picric Acid	31	21.5	20	Picric Acid	30	20.5	20
Torpedin-2	50	40.5	40	Torpedin-2	50	39.5	40
DBE	60	45.5	40	DBE	60	41.5	41
Composition B	60	45.5	40	DBE	70	46.5	40
Mono-2	65	47.5	40	Composition B	70	46.5	40
UNR	117.5	89.5	70	UNR	137	86.5	87
TNT	131.5	100.5	100	TNT	140	100.5	100

TABLE 13
SUMMARY OF TEST DATA SHOWING THE EFFECT OF ADDED GRIT

Grit Screened through 10 mesh on 100 mesh										Grit Screened through 100 mesh on 100 mesh									
Drop Height (Cm.)	Log Drop Height	Ave SE	Ave SE	Ave SE	Ave SE	Ave SE	Ave SE	Ave SE	Ave SE	Ave SE	Ave SE	Ave SE	Ave SE	Ave SE	Ave SE	Drop Height (Cm.)	Log Drop Height		
2	0.301															2	0.301		
5	0.690			0	2.5	15	3				5	2.5	5			5	0.692		
10	0.778			2.5	12.5	68	5				20	20	68	5		10	0.778		
15	0.903		10	25	50	12.5	12.5				0	47.5	40	2.5	2.5	15	0.903		
100	1.000	0	5	30	62.5	75	2.5				10	30.5	67.5	15	27.5	100	1.000		
15	1.176	27.5	75	72.5	67.5	100	52.5	50	25	75	92.5	87.5	62.5	68	15	1.176			
20	1.301	75	92.5	97.5	100	80	28.5	67.5	92.5	97.5	100	90	90	20	20	1.301			
30	1.577	95		100		57.5	20	92	100	100		100	60	30	30	1.577			
50	1.662						17.5	100					47.5	50	50	1.662			
50	1.690						12.5						75	50	50	1.690			
75	1.875						100						90	75	75	1.875			

TABLE 14
SUMMARY OF TEST DATA SHOWING THE EFFECT OF ADDED GRIT

Grit Screened through 10 mesh on 100 mesh										Grit Screened through 100 mesh on 200 mesh									
Drop Height (Cm.)	Lag Drop Height	Ave SE	Ave SE	Ave SE	Ave SE	Ave SE	Ave SE	Ave SE	Ave SE	Ave SE	Ave SE	Ave SE	Ave SE	Ave SE	Drop Height (Cm.)	Lag Drop Height			
5	0.310														5	0.310			
5	0.961			50						50	7.40	50	50		5	0.961			
10	1.000		0	2.5	20	20				5	7.5	20	5	10	1.000				
15	1.340		12.5	50	2.5	27.5				15	27.5	50	27.5	50	1.340				
20	1.67		15	50	50.5	50	50	17.5	52.5	57.5	52.5	50		50	1.67				
25	1.992			57.5	72.5	50.5	52.5	15	55	57.5	55	50	22.5	50	1.992				
30	2.300	0		57.5	50	2.5	50	52.5	52.5	55	75	55	5	50	2.300				
35	2.675	7.5		52.5	50	57.5	50	57.5	75.5	57.5	50	57.5	50	75	2.675				
100	2.900	20.000	100					75	50	57.5		57.5		100	2.900				
150	2.170	50.5								57.5				150	2.170				
200	2.501	50						100					100	200	2.501				

TABLE XI
**SUMMARY OF DATA FOR THE EFFECT OF CHARGE WEIGHT ON THE AVERAGE
% EXPLOSIONS**

[illegible]

*** 10 Trials, all others 20 trials**

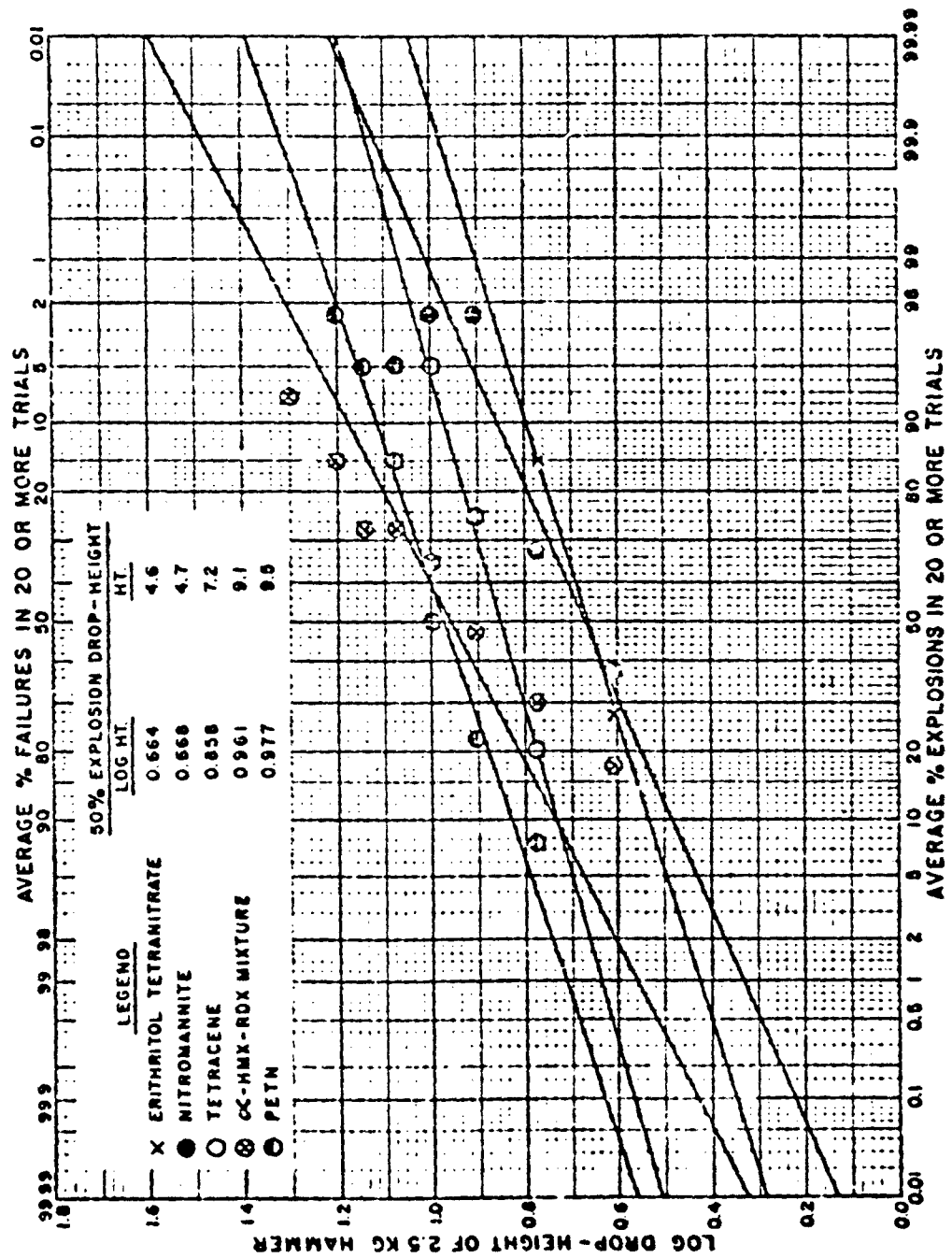


FIG. 1 COMPARATIVE SENSITIVITIES OF CLASS I EXPLOSIVES BY DESIGN NO. 12

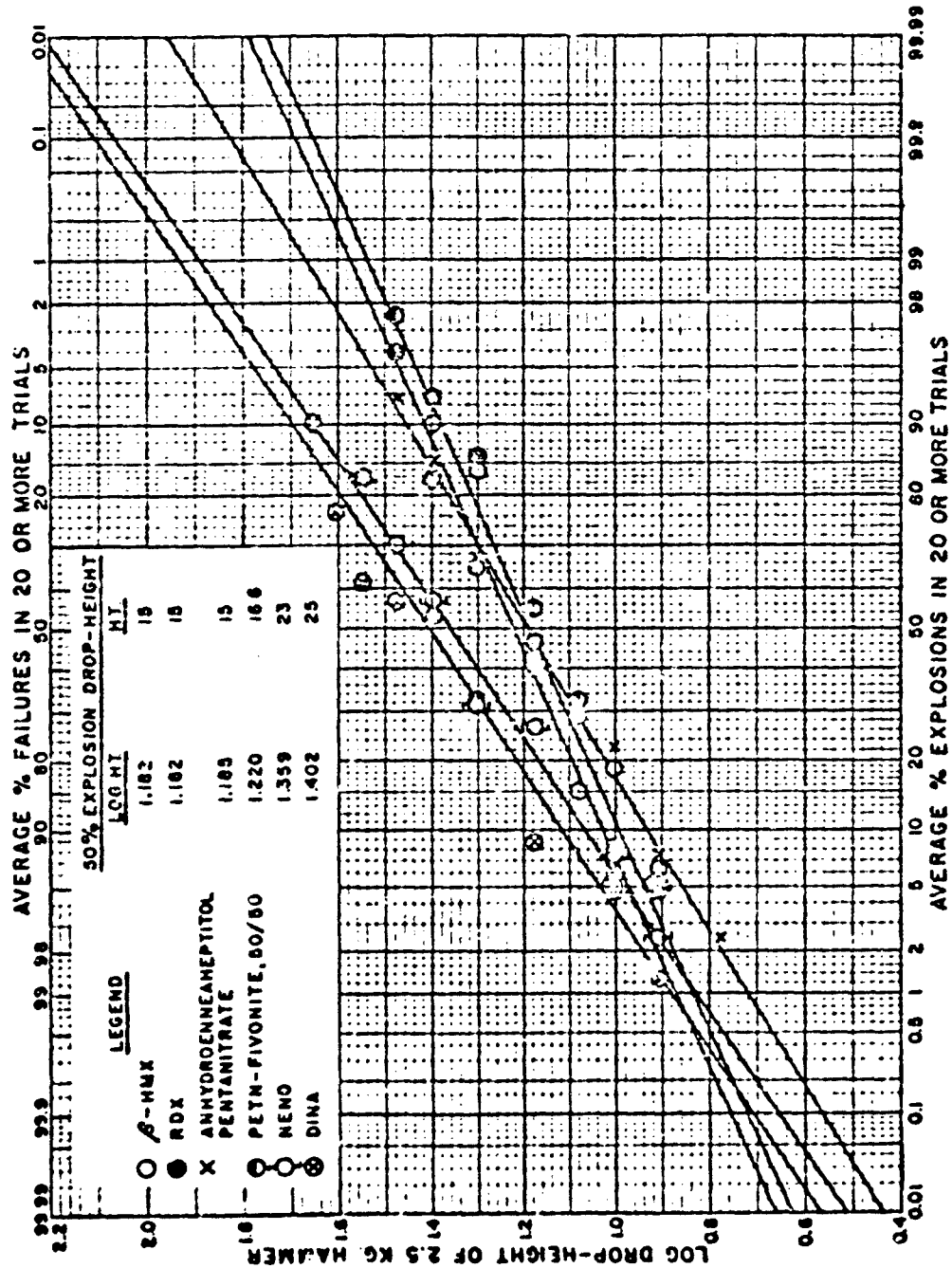


FIG.2 COMPARATIVE SENSITIVITIES OF CLASS I EXPLOSIVES BY DESIGN NO.12

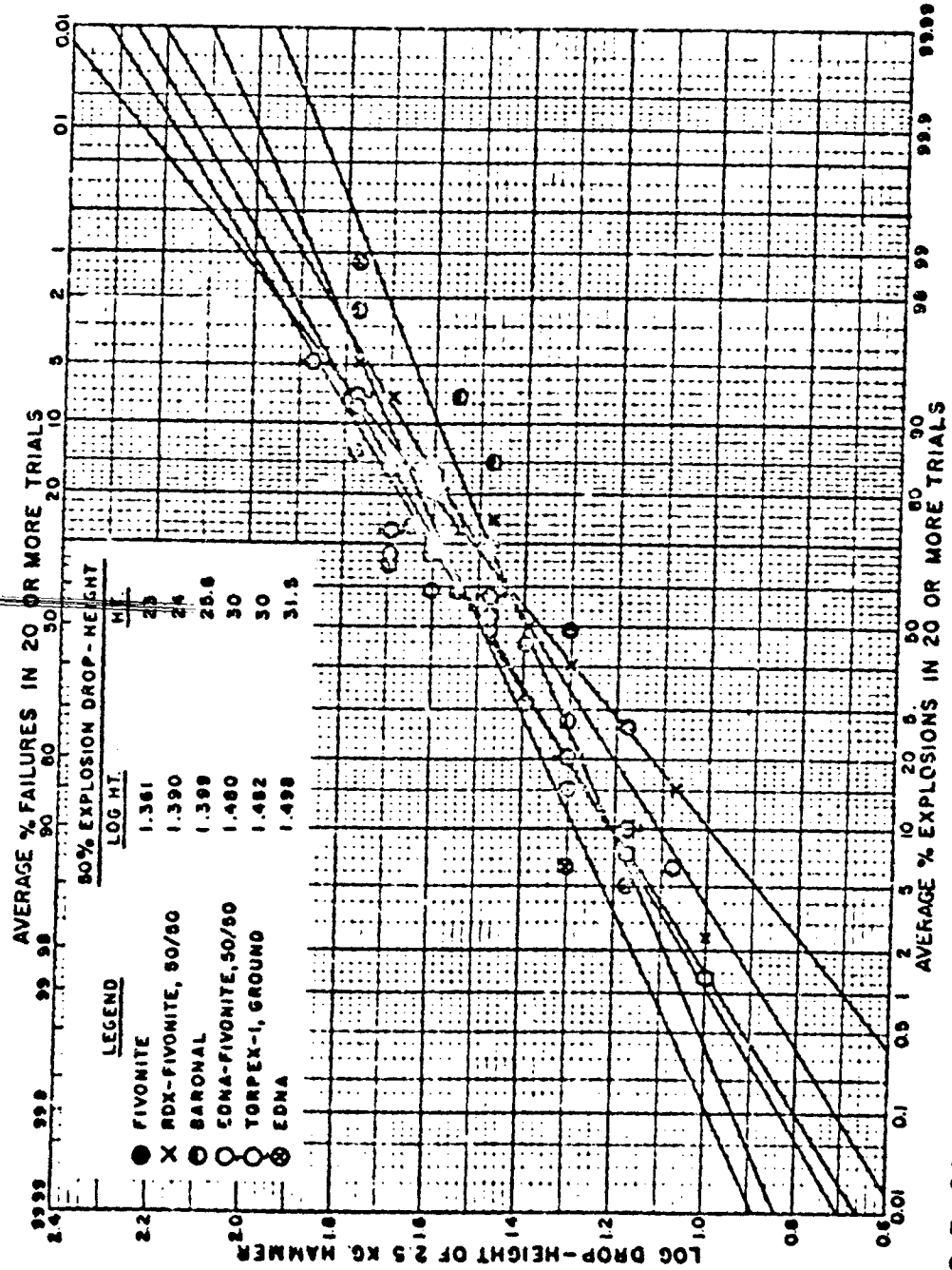


FIG. 3 COMPARATIVE SENSITIVITIES OF CLASS II EXPLOSIVES BY DESIGN NO. 12

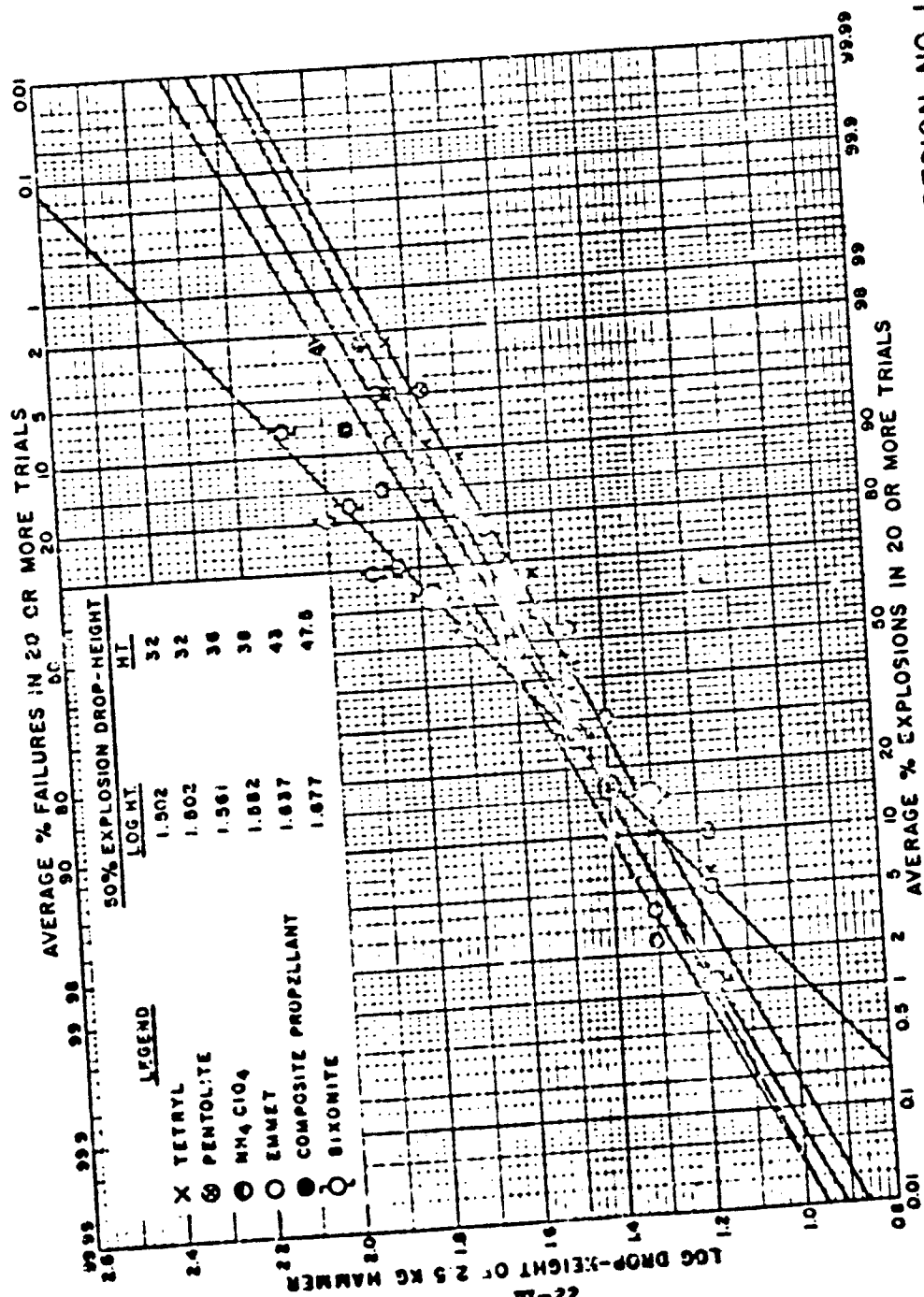


FIG. 4 COMPARATIVE SENSITIVITIES OF CLASS II EXPLOSIVES BY DESIGN NO. 12

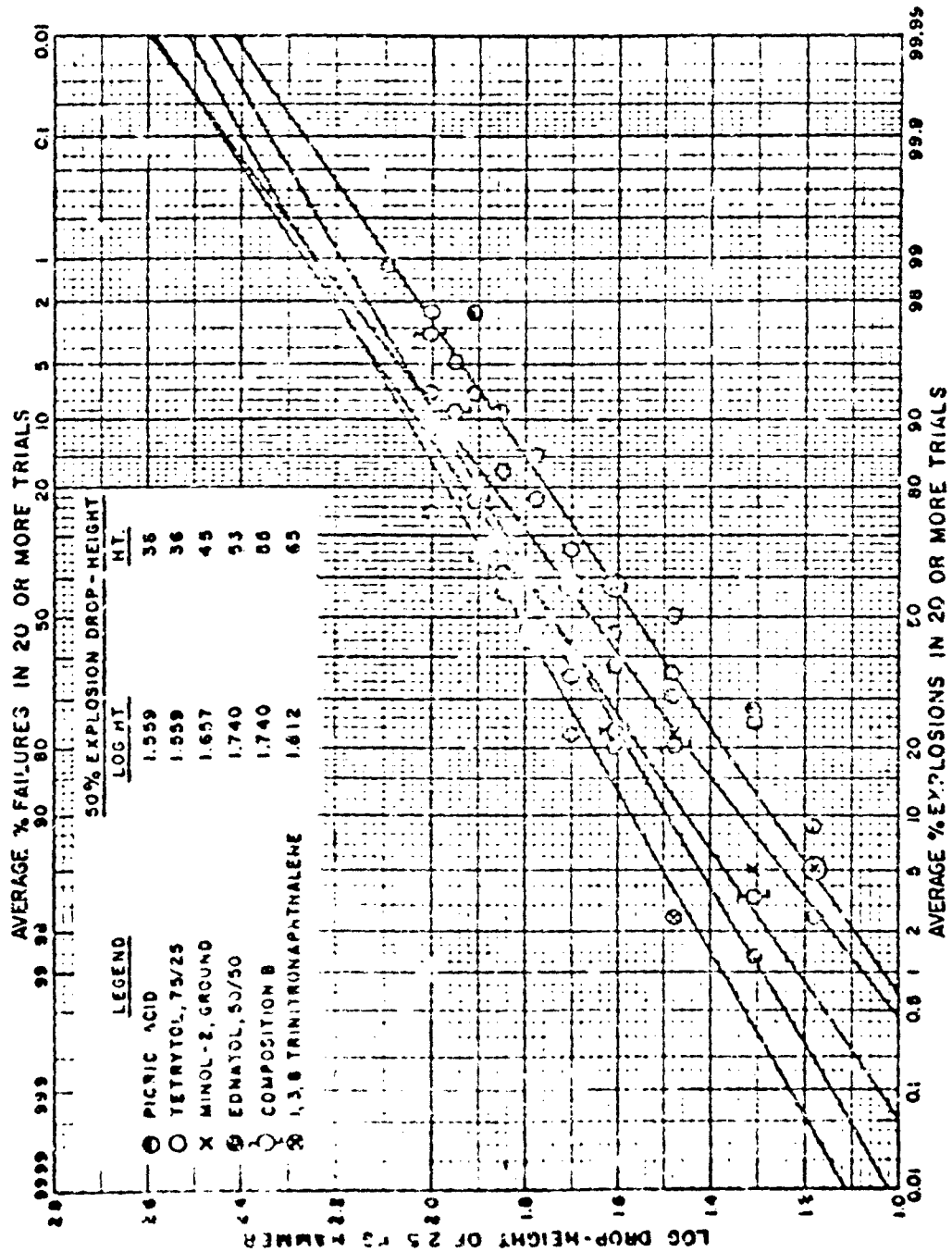
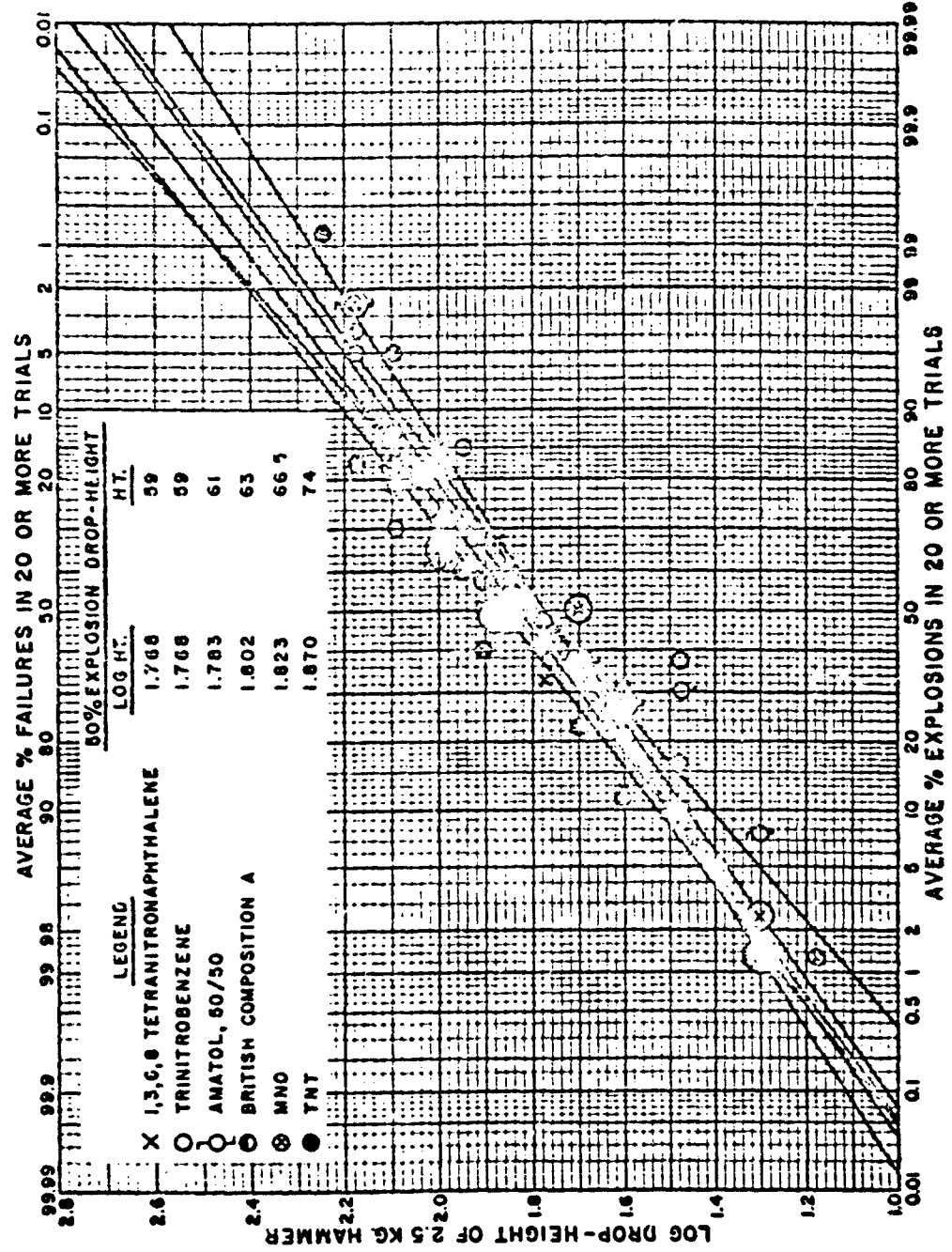


FIG.5 COMPARATIVE SENSITIVITIES OF CLASS III EXPLOSIVES BY DESIGN NO.12



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FIG. 6 COMPARATIVE SENSITIVITIES OF CLASS III EXPLOSIVES BY DESIGN NO. 12

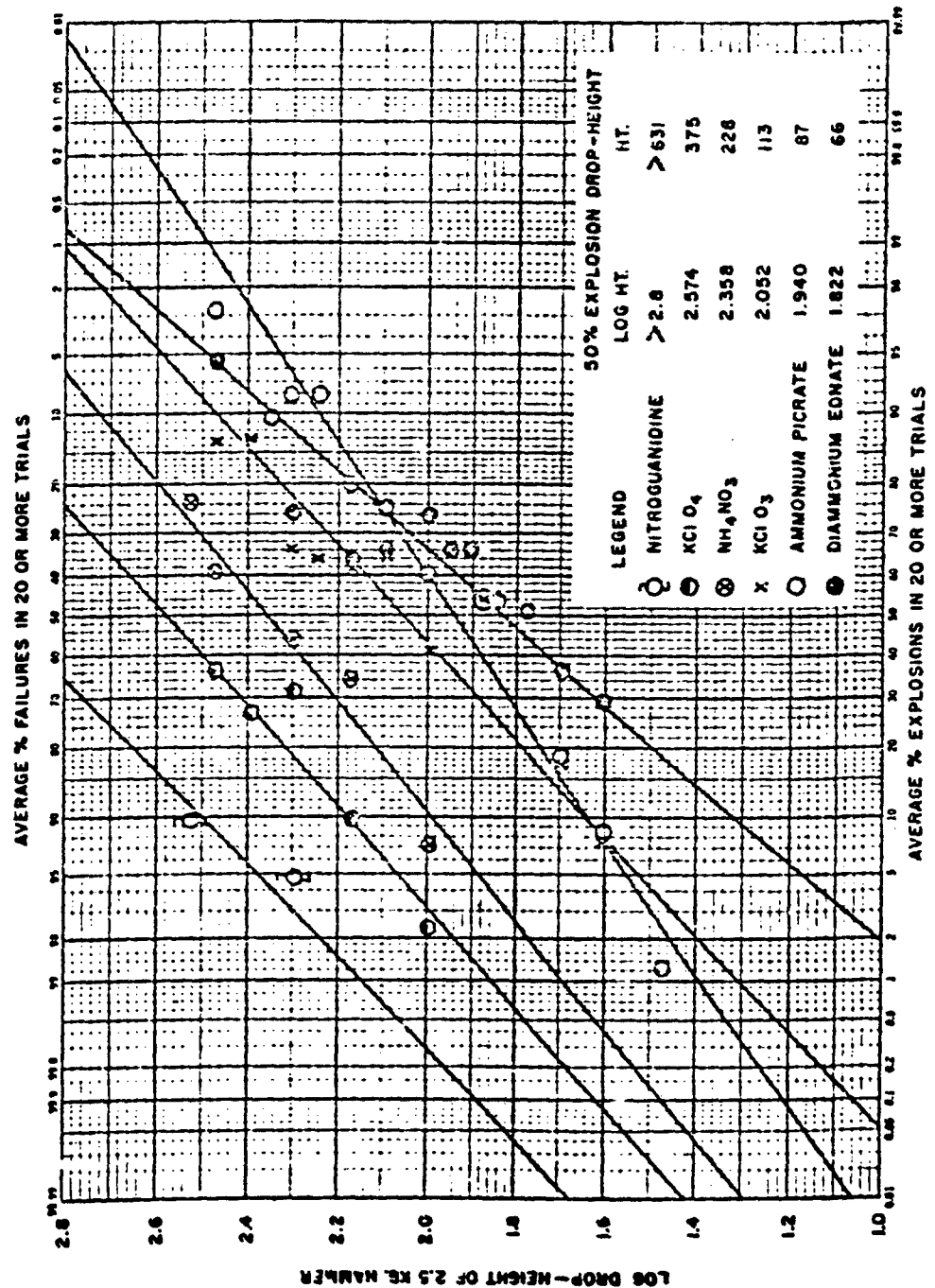


FIG. 7 COMPARATIVE SENSITIVITIES OF CLASS IV EXPLOSIVES BY DESIGN NO.12

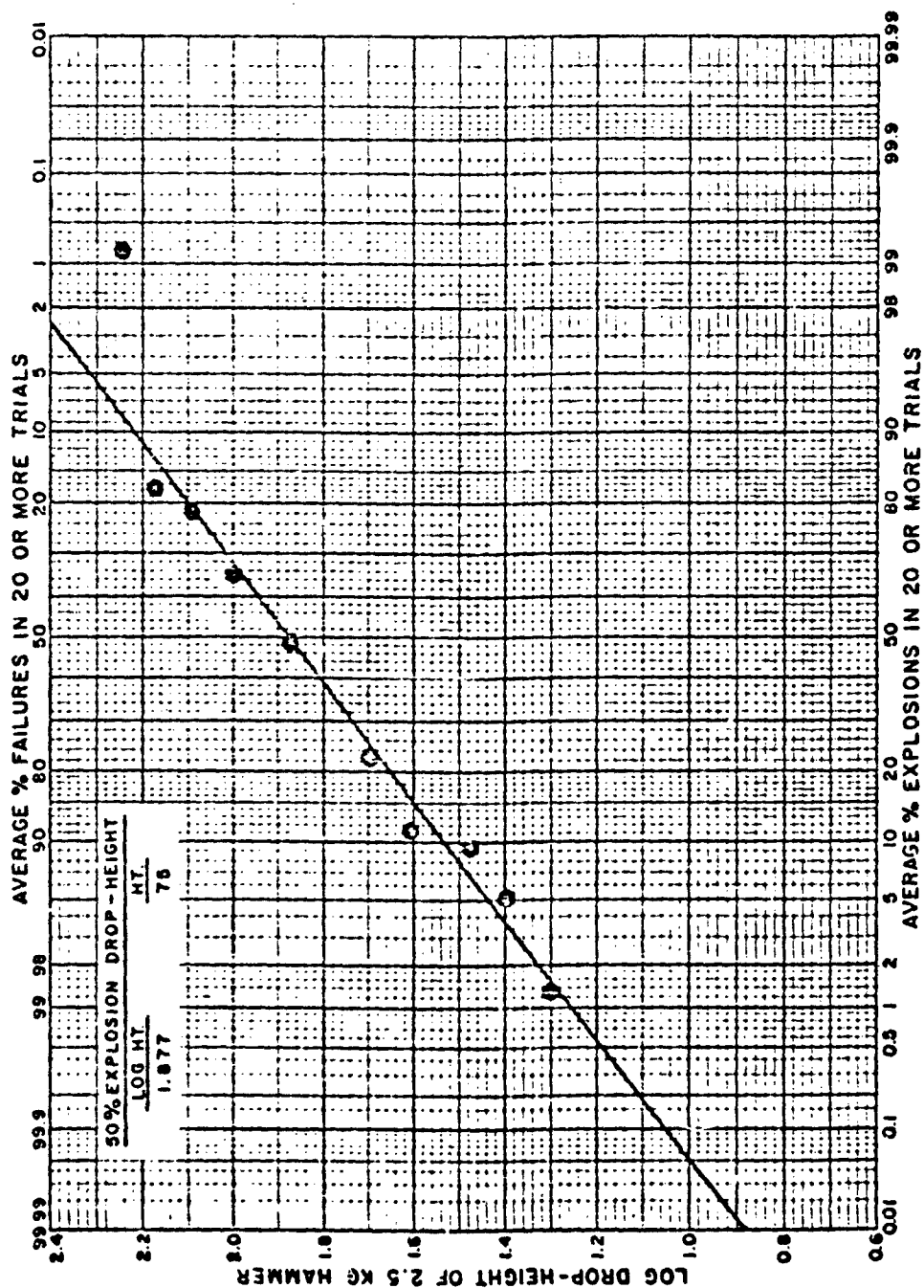
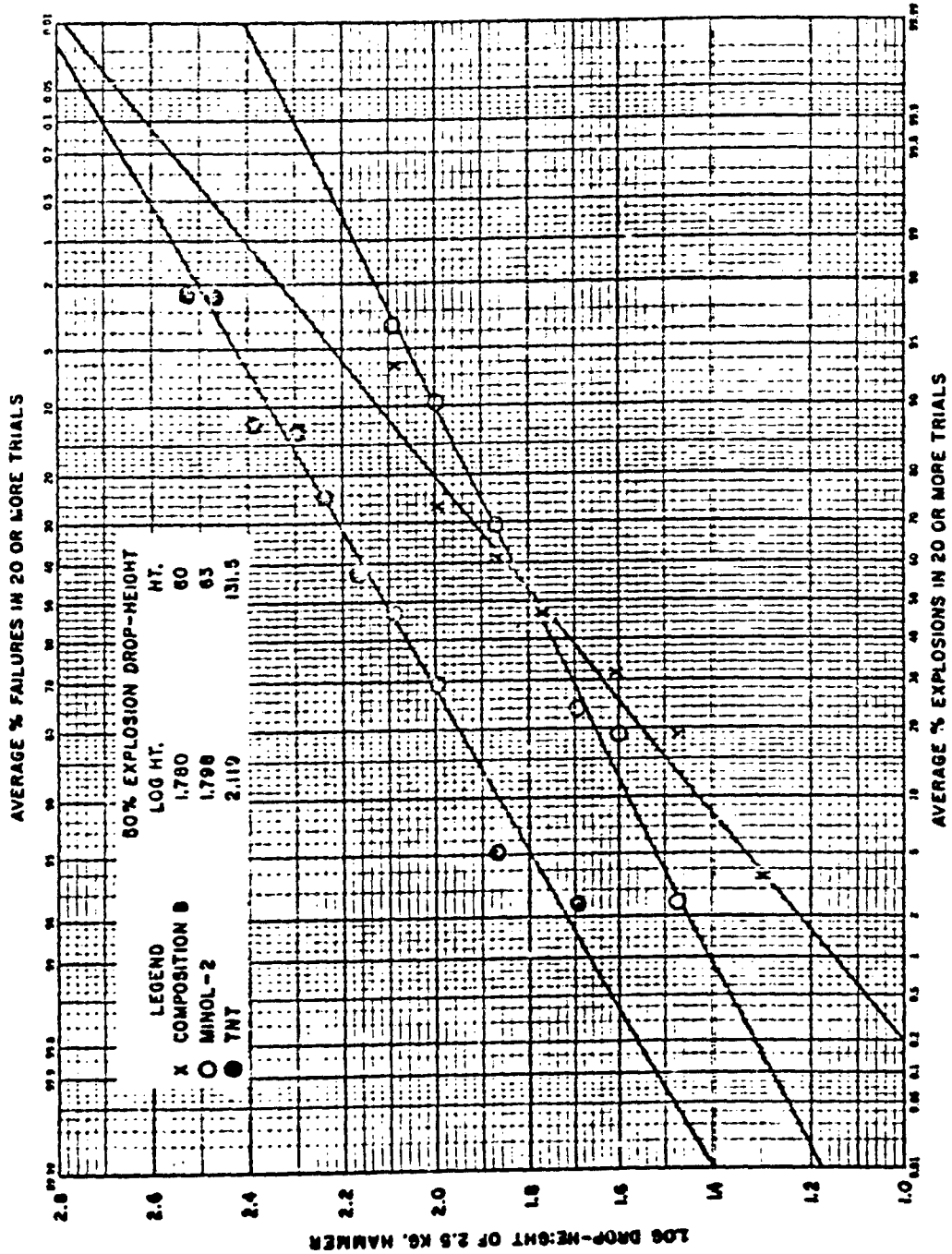


FIG. 8 REFERENCE CURVE FOR SENSITIVITY OF TRINITROTOLUENE AS STUDIED BY DESIGN NO. 12



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FIG. 9 COMPARATIVE SENSITIVITIES OF COARSE (SCREENED THROUGH 16 MESH ON 50 MESH) MATERIALS AS STUDIED BY DESIGN NO. 12

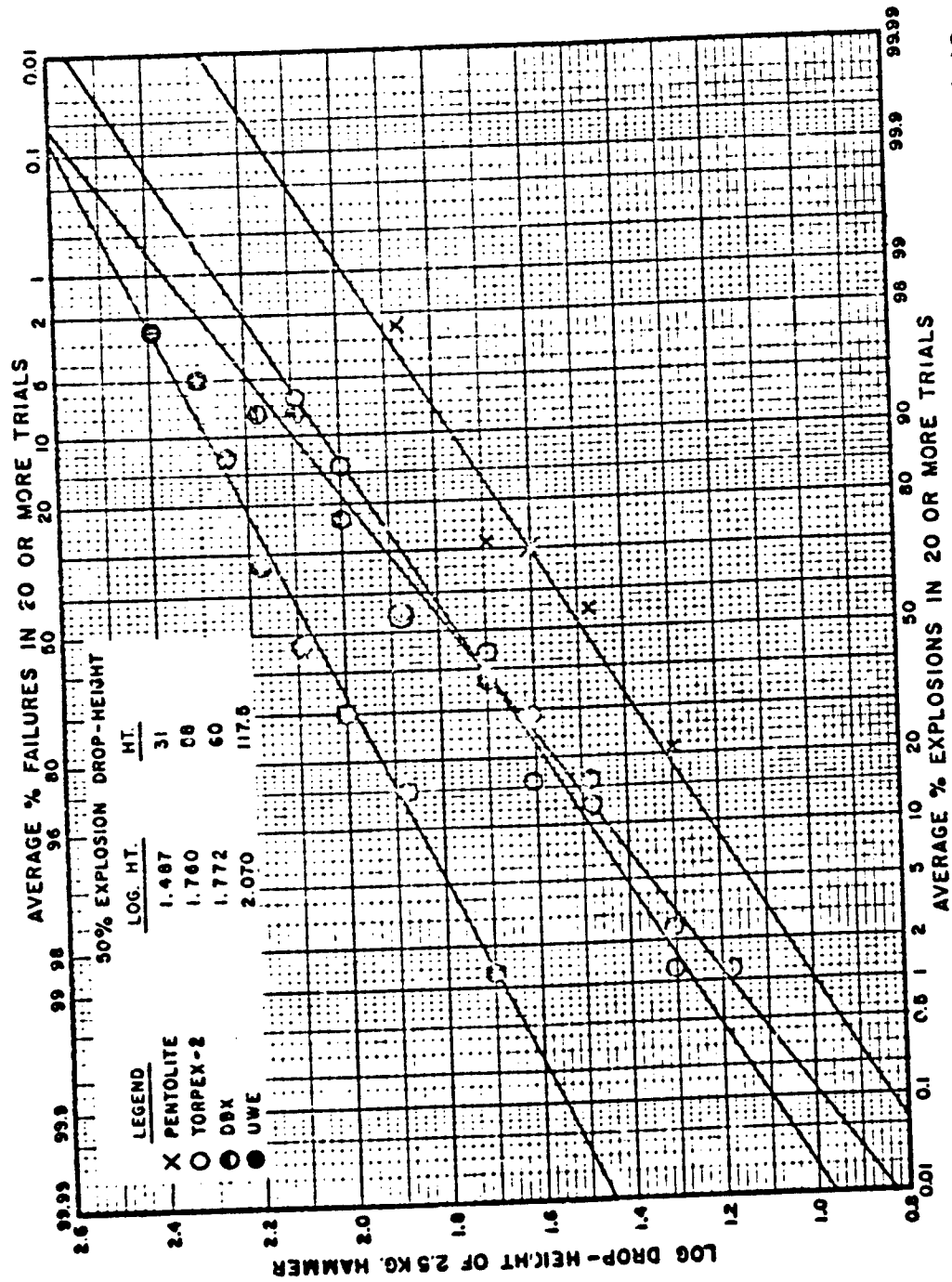


FIG. 10 COMPARATIVE SENSITIVITIES OF COARSE (SCREENED THROUGH 16 MESH ON 50 MESH) MATERIALS AS STUDIED BY DESIGN NO. 12

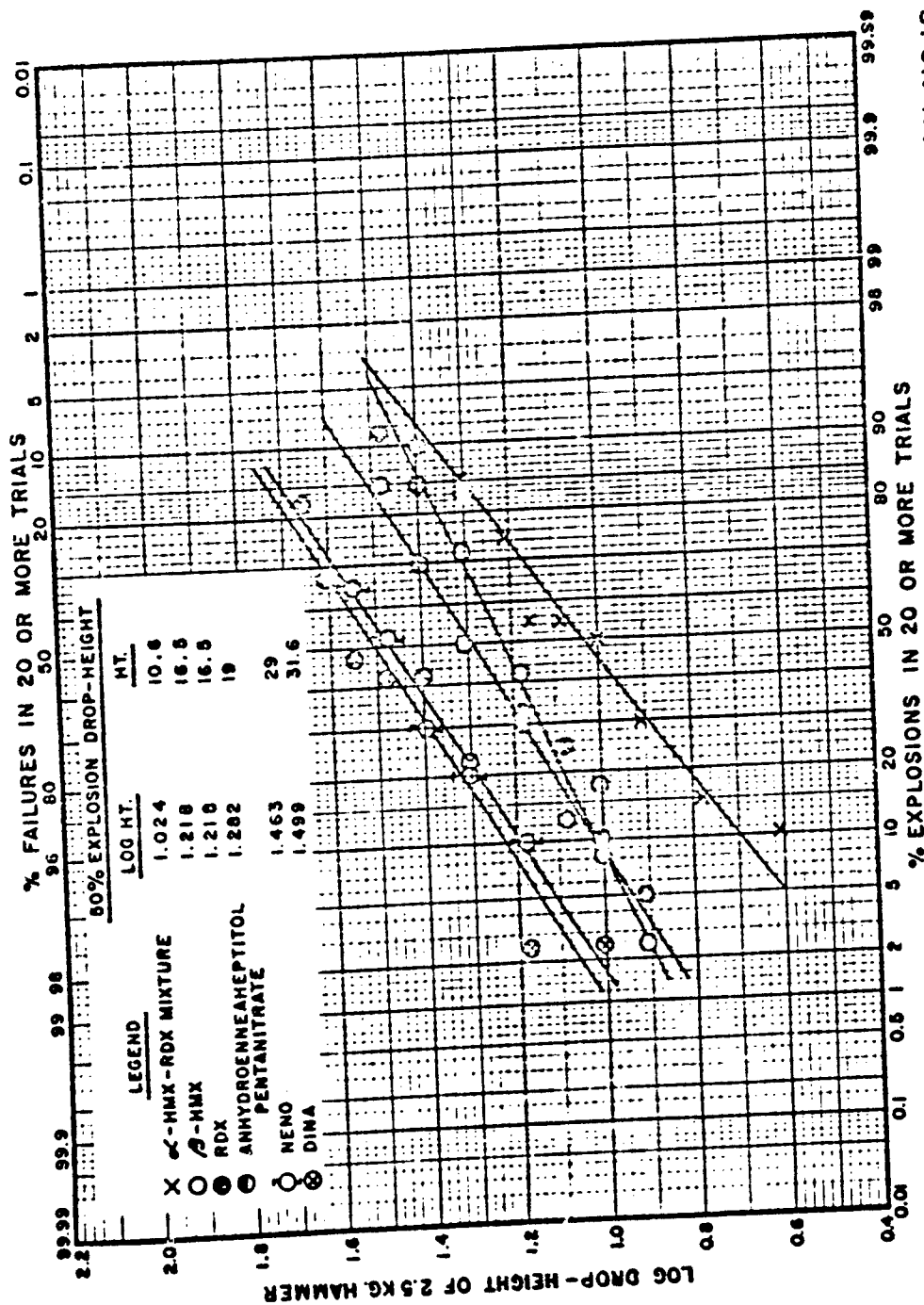
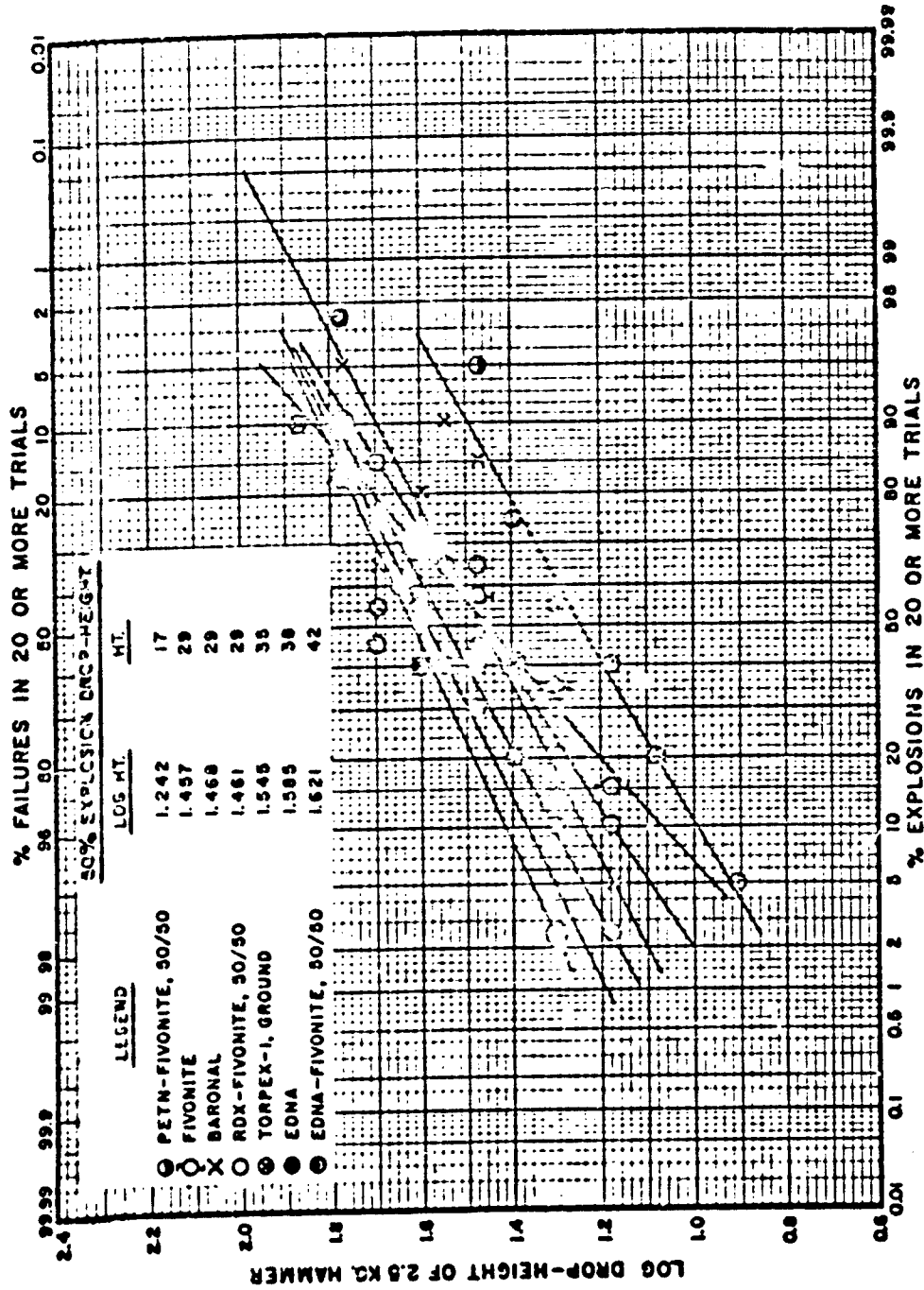


FIG. II COMPARATIVE SENSITIVITIES OF CLASS I EXPLOSIVES BY DESIGN NO. 12,
DOUBTFUL EXPLOSIONS BEING COUNTED AS FAILURES

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FIG. 12 COMPARATIVE SENSITIVITIES OF CLASS II (ONE CLASS I) EXPLOSIVES BY DESIGN
NQ.12, DOUBTFUL EXPLOSIONS BEING COUNTED AS FAILURES

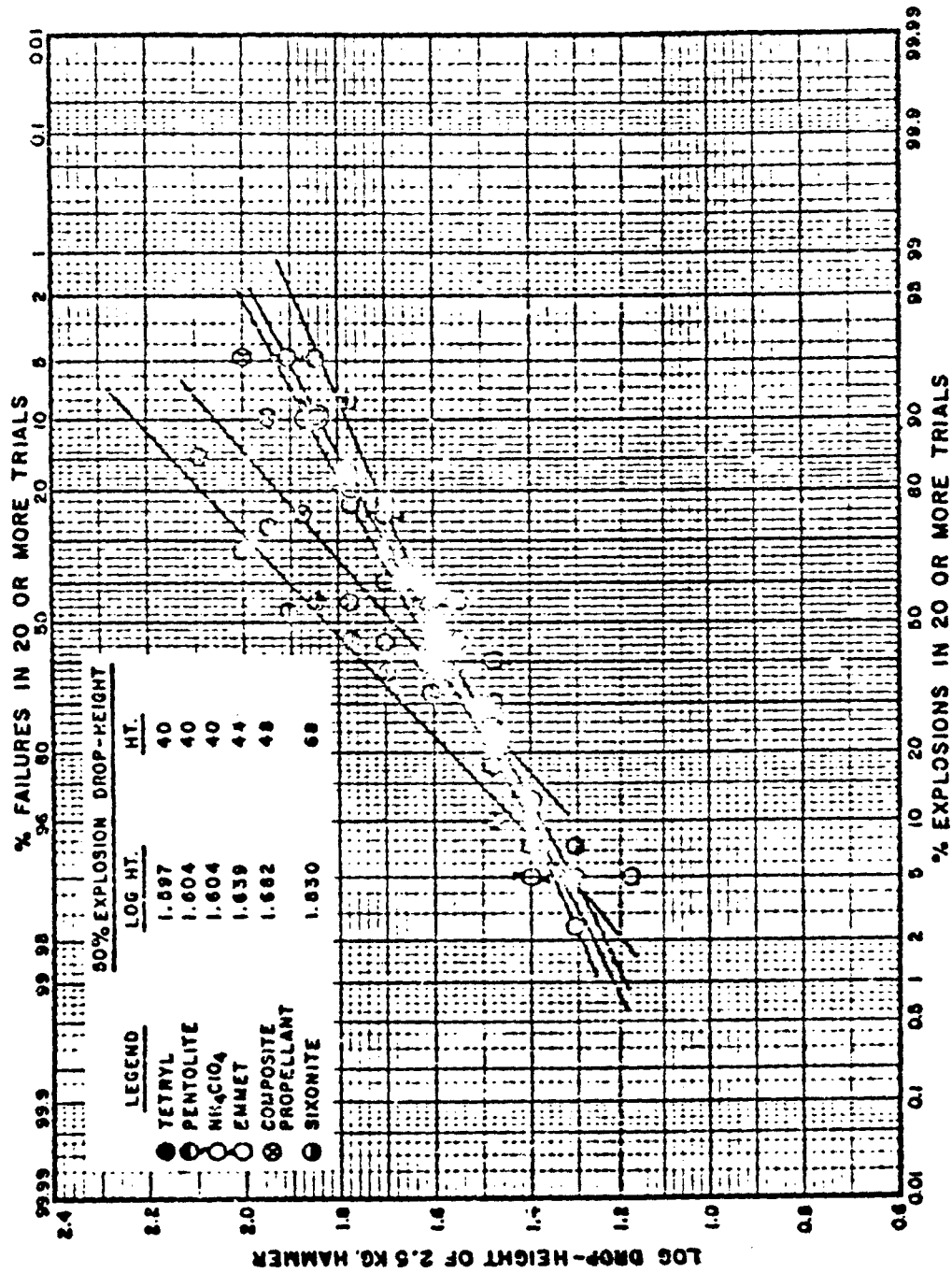


FIG.13 COMPARATIVE SENSITIVITIES OF CLASS II EXPLOSIVES BY DESIGN NO.12.
DOUBTFUL EXPLOSIONS BEING COUNTED AS FAILURES

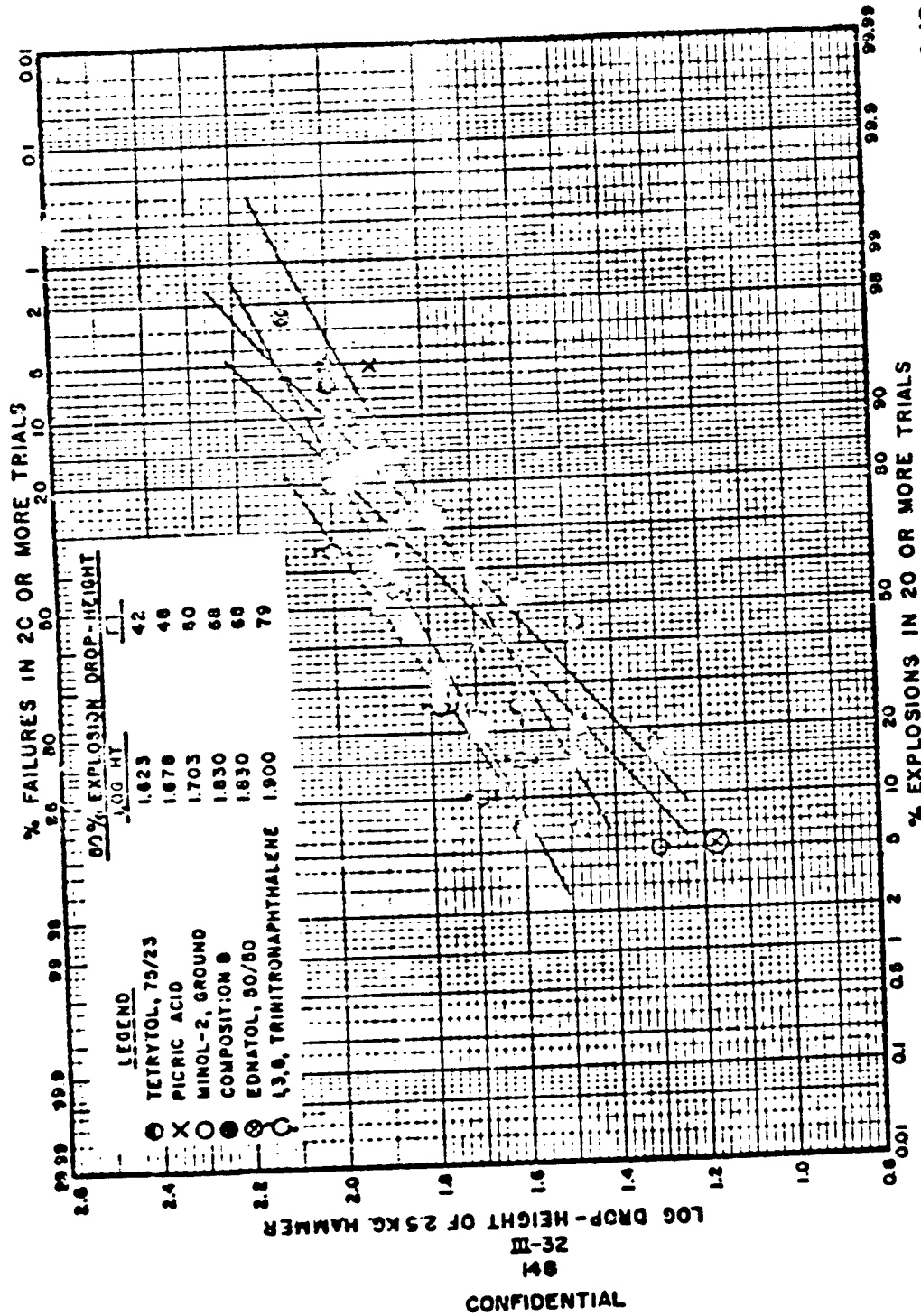


FIG.14 COMPARATIVE SENSITIVITIES OF CLASS III EXPLOSIVES BY DESIGN NO.12,
DOUBTFUL EXPLOSIONS BEING COUNTED AS FAILURES

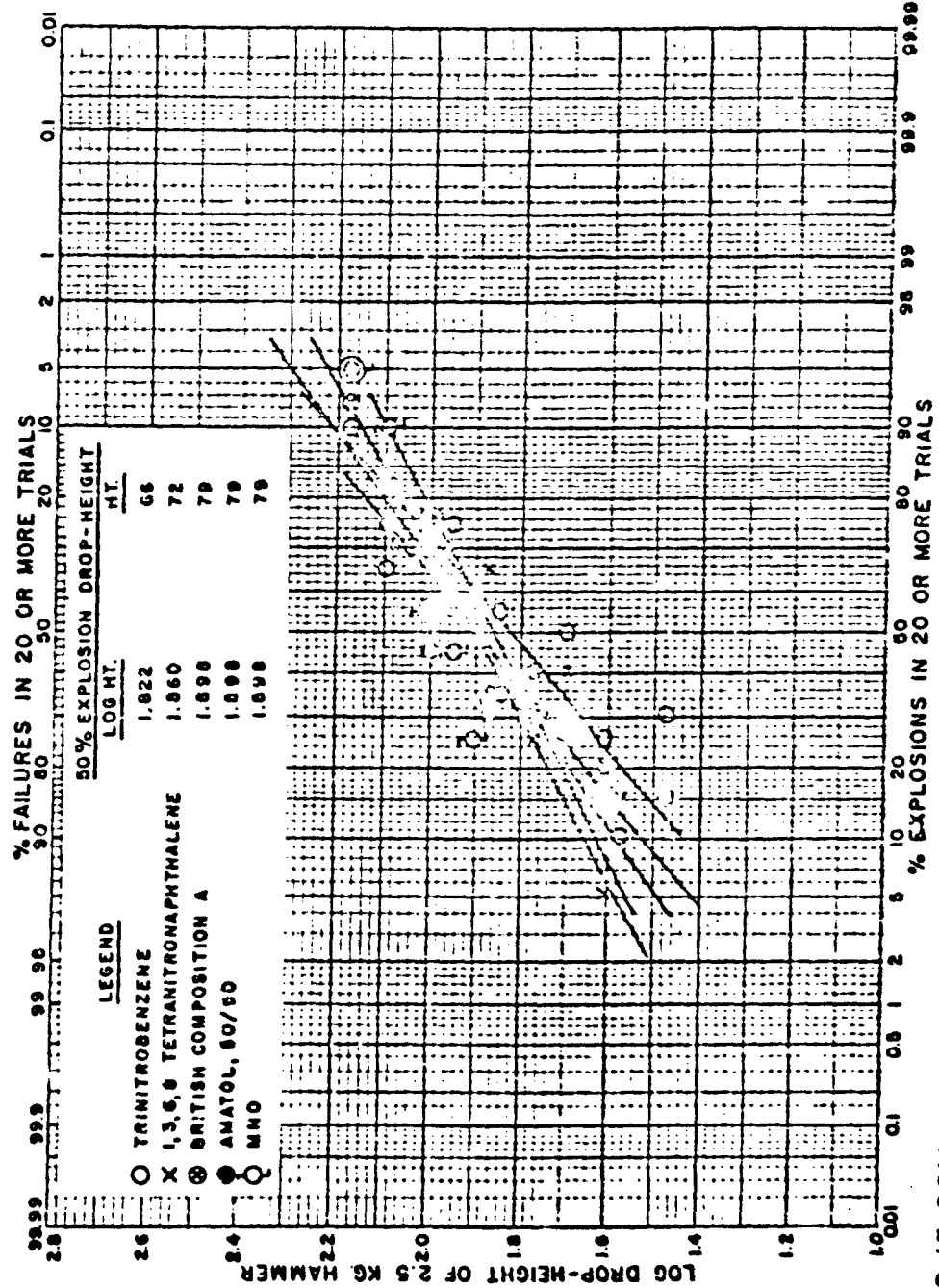
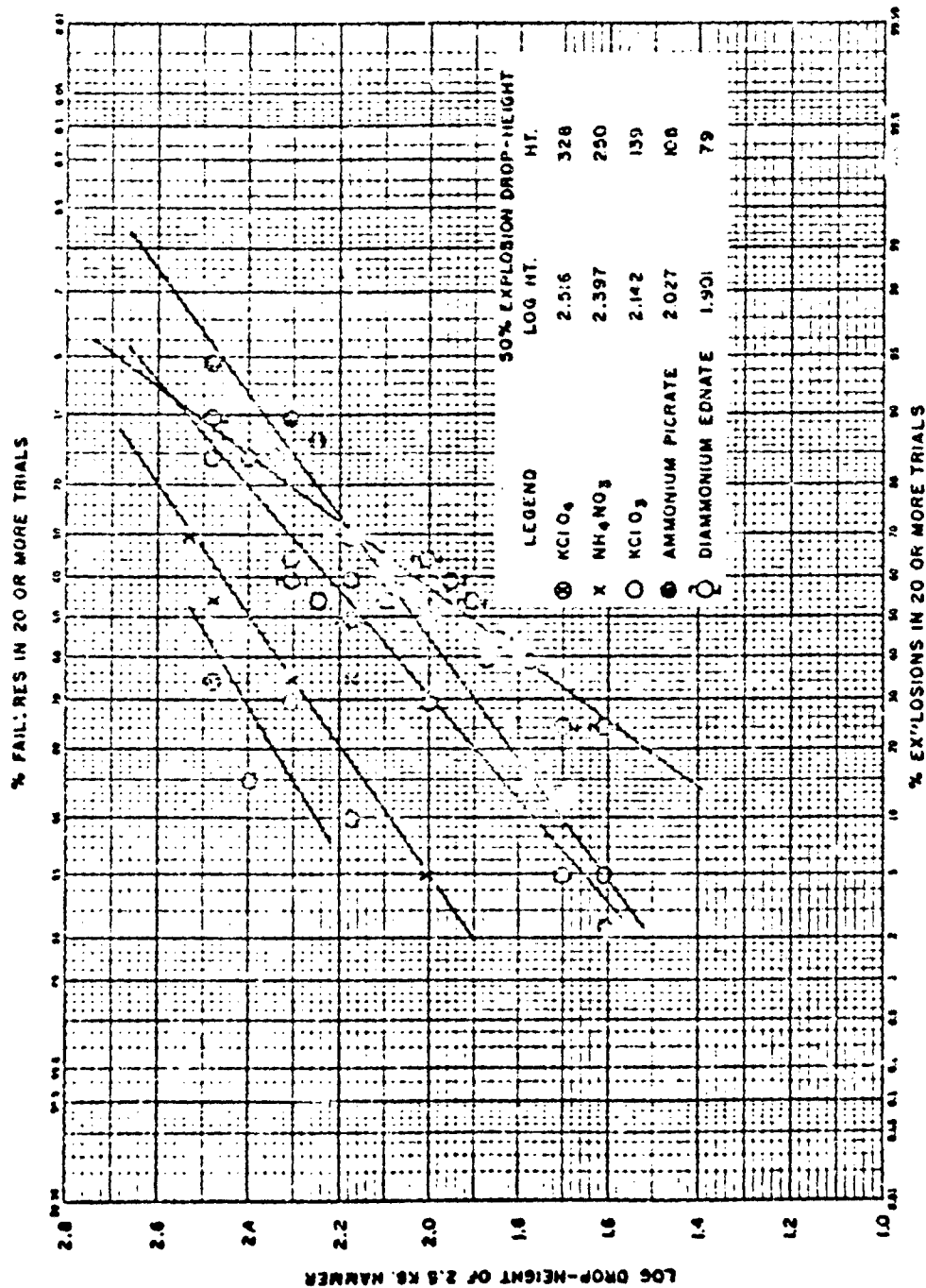


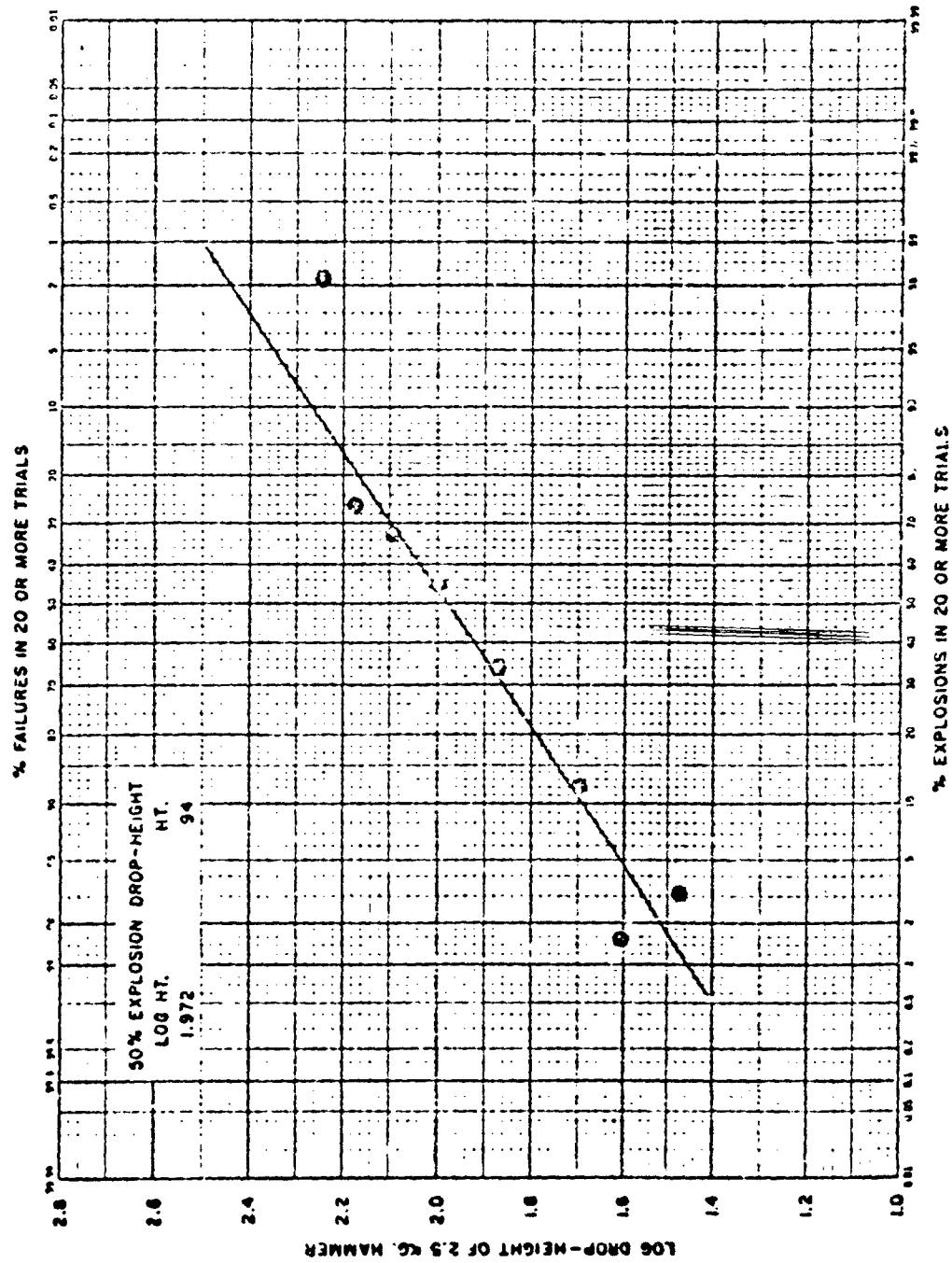
FIG. 15 COMPARATIVE SENSITIVITIES OF CLASS III EXPLOSIVES BY DESIGN NO. 12, DOUBTFUL EXPLOSIONS BEING COUNTED AS FAILURES.



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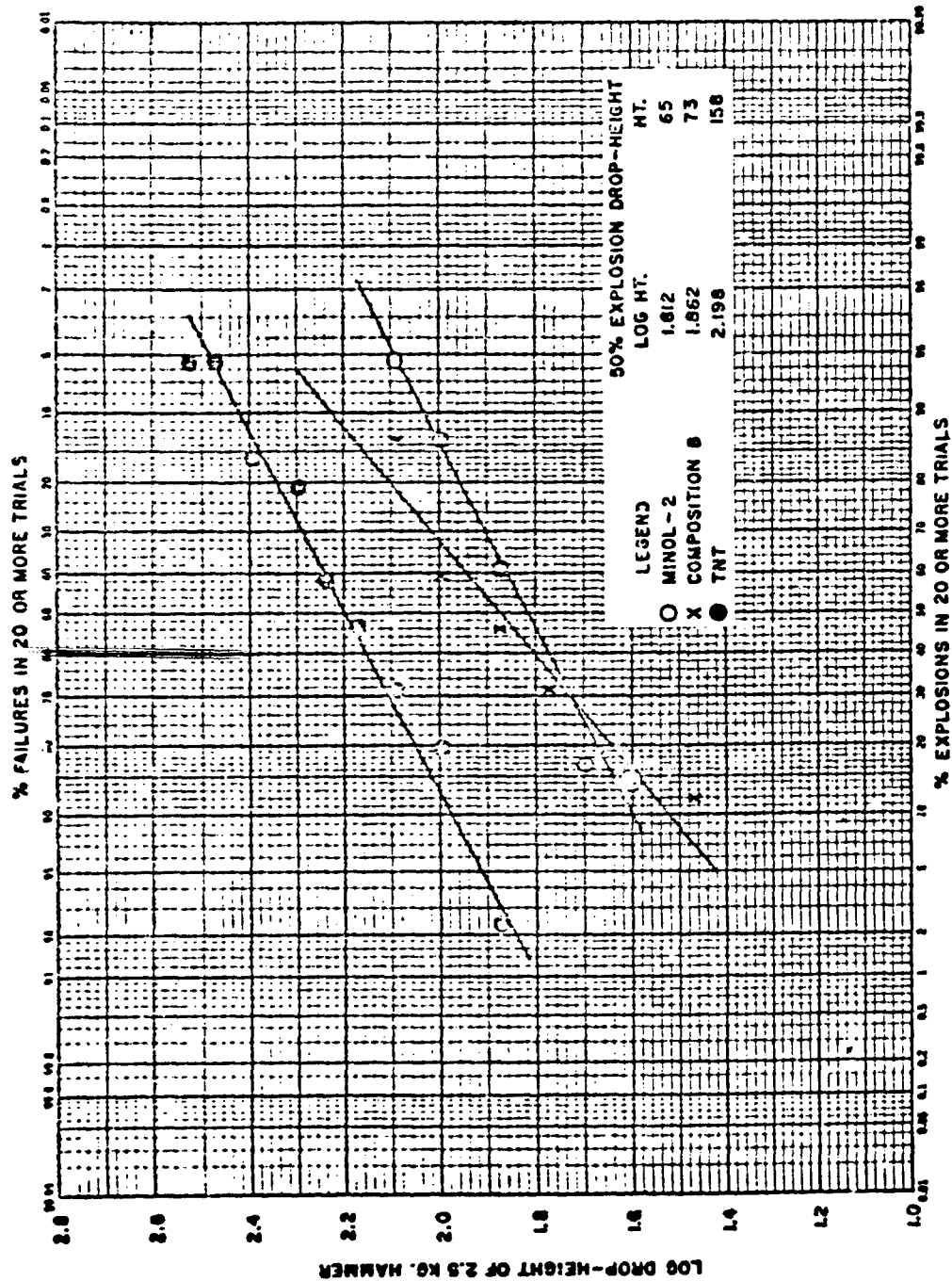
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FIG.16 COMPARATIVE SENSITIVITIES OF CLASS IV EXPLOSIVES BY DESIGN NO. 12, DOUBTFUL EXPLOSIONS BEING COUNTED AS FAILURES



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FIG. 17 REFERENCE CURVE FOR SENSITIVITY OF TRINITROTOLUENE AS STUDIED BY DESIGN NO. 12,
DOUBTFUL EXPLOSIONS BEING COUNTED AS FAILURES



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FIG.18 COMPARATIVE SENSITIVITIES OF COARSE (SCREENED THROUGH 16 MESH ON 50 MESH) MATERIALS
AS STUDIED BY DESIGN NO.12, DOUBTFUL EXPLOSIONS BEING COUNTED AS FAILURES

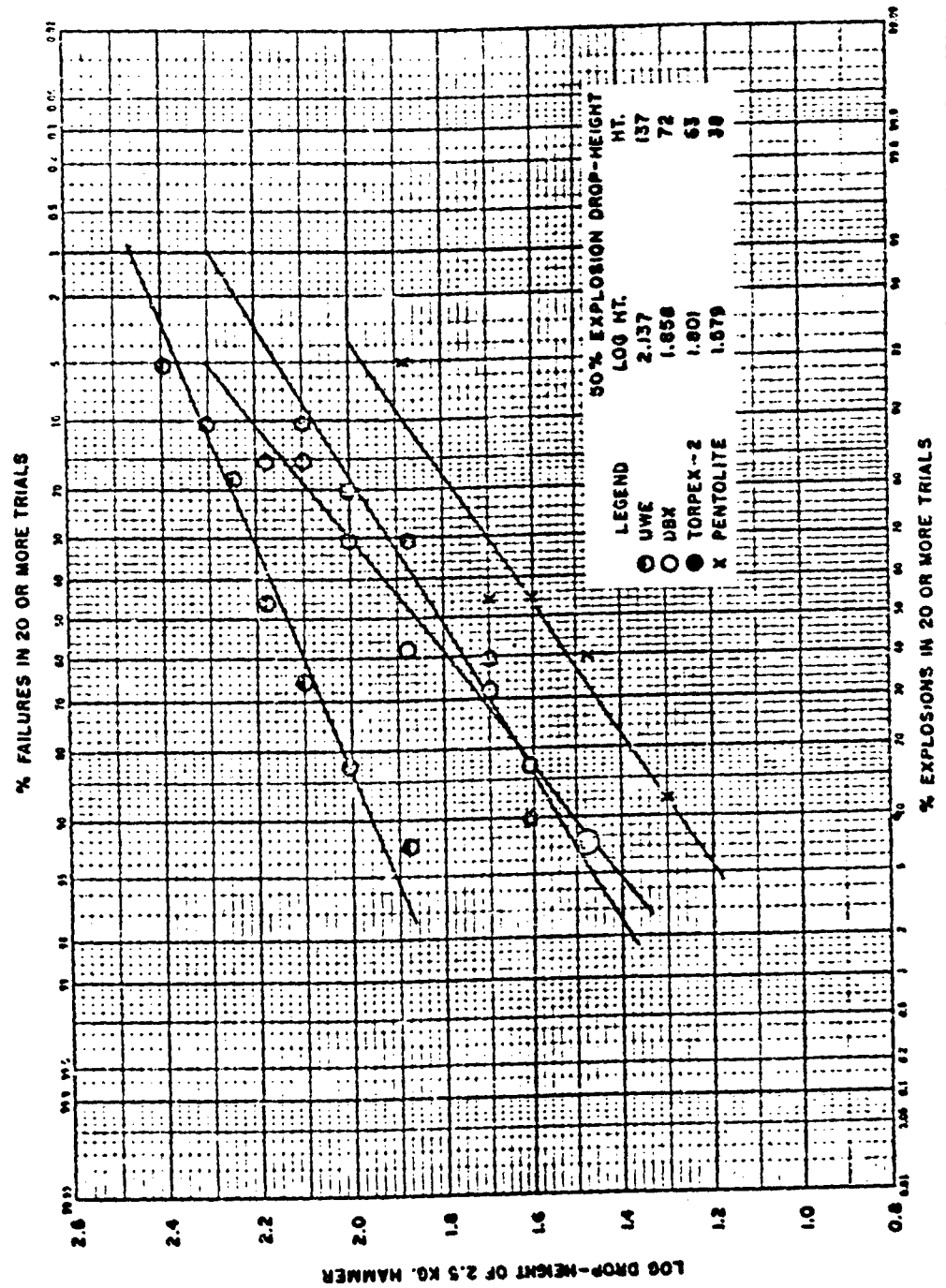


FIG. 19 COMPARATIVE SENSITIVITIES OF COARSE (THROUGH 16 ON 50 MESH) MATERIALS AS STUDIED BY DESIGN NO. 12, DOUBTFUL EXPLOSIONS BEING COUNTED AS FAILURES

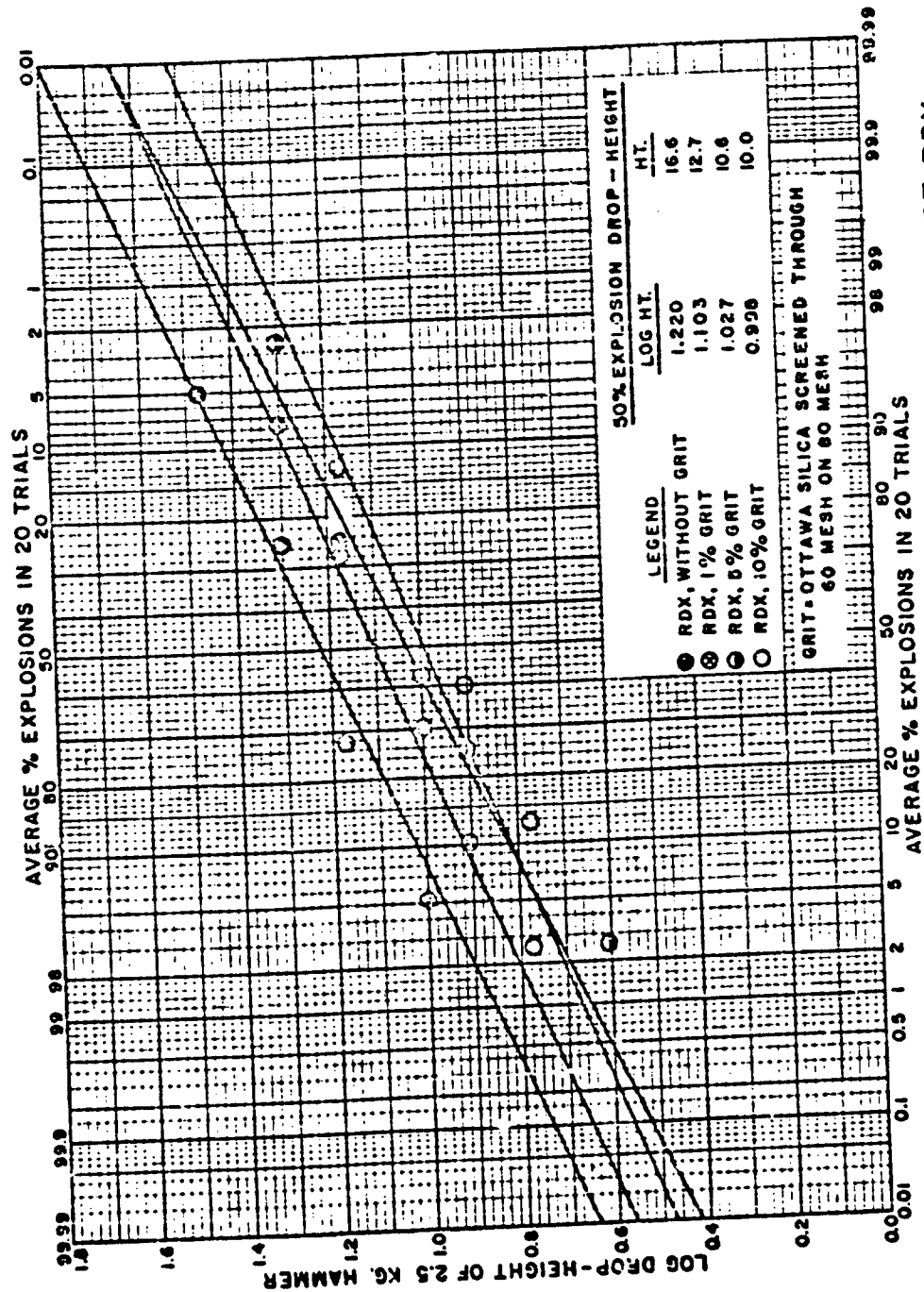


FIG. 20 THE EFFECT OF ADDED GRIT ON THE SENSITIVITY OF RDX, AS STUDIED BY DESIGN NO. 12

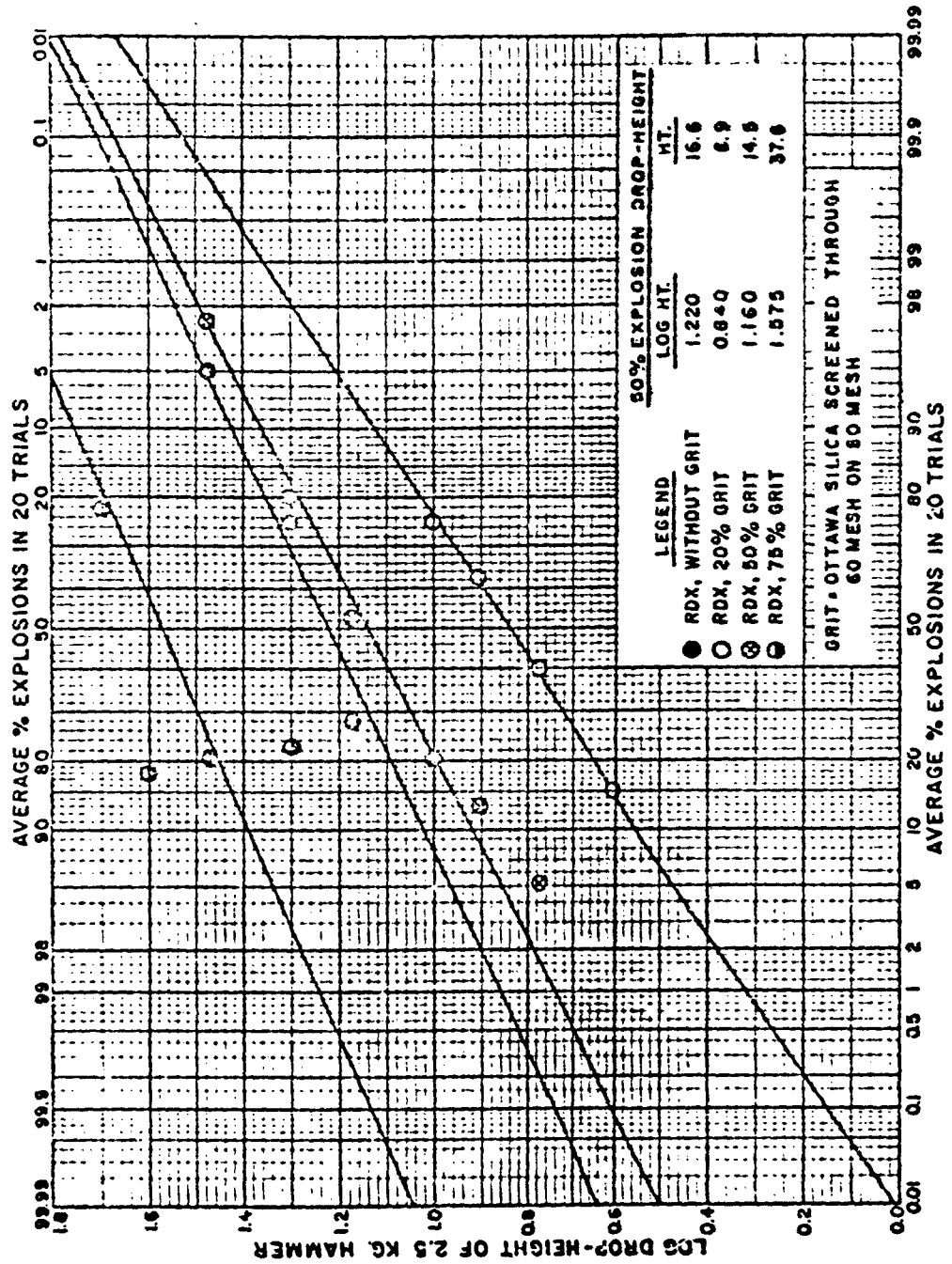


FIG. 21 THE EFFECT OF ADDED GRIT ON THE SENSITIVITY OF RDX
AS STUDIED BY DESIGN NO 12

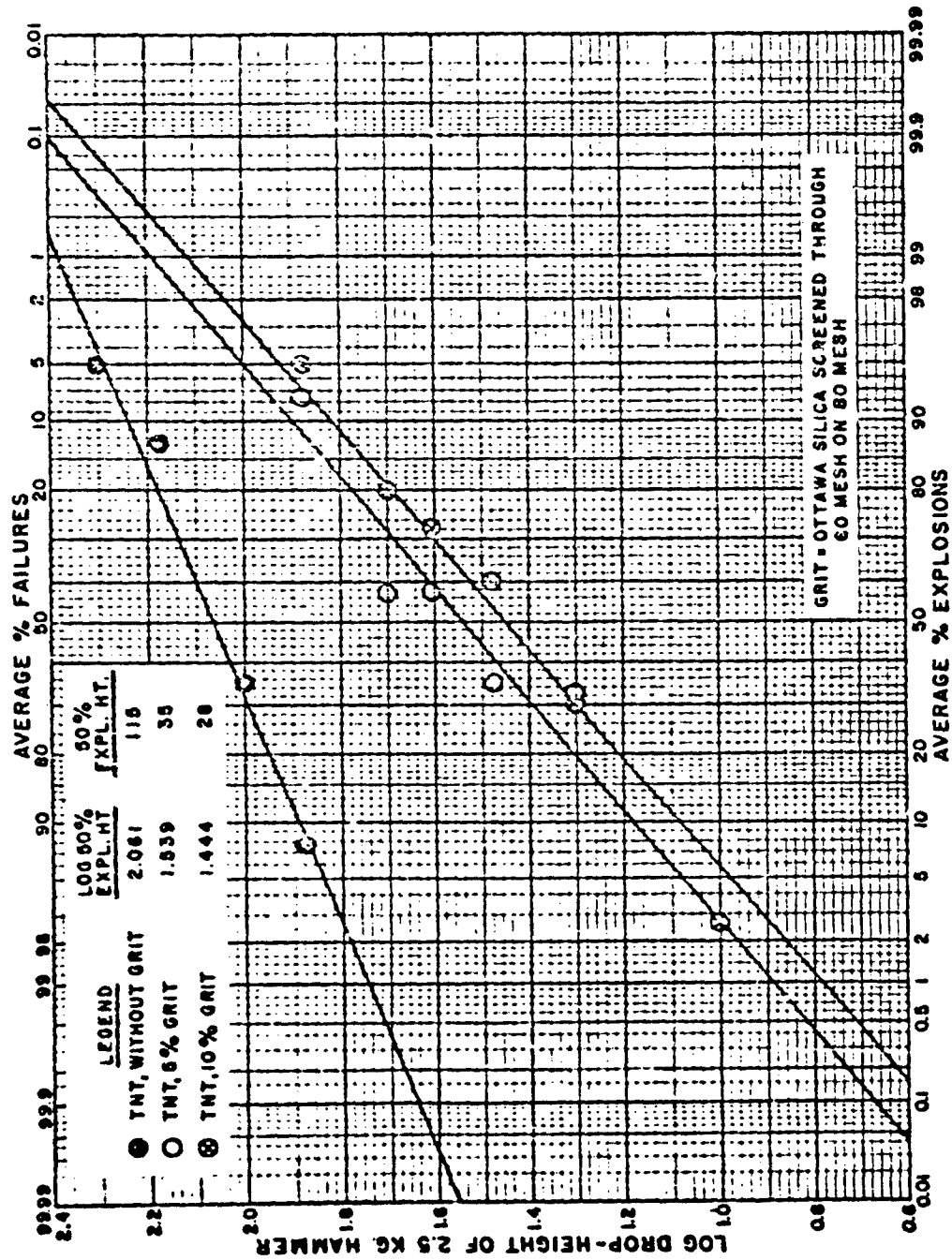


FIG. 22 THE EFFECT OF ADDED GRIT ON THE SENSITIVITY OF TNT,
AS STUDIED BY DESIGN NO. 1.

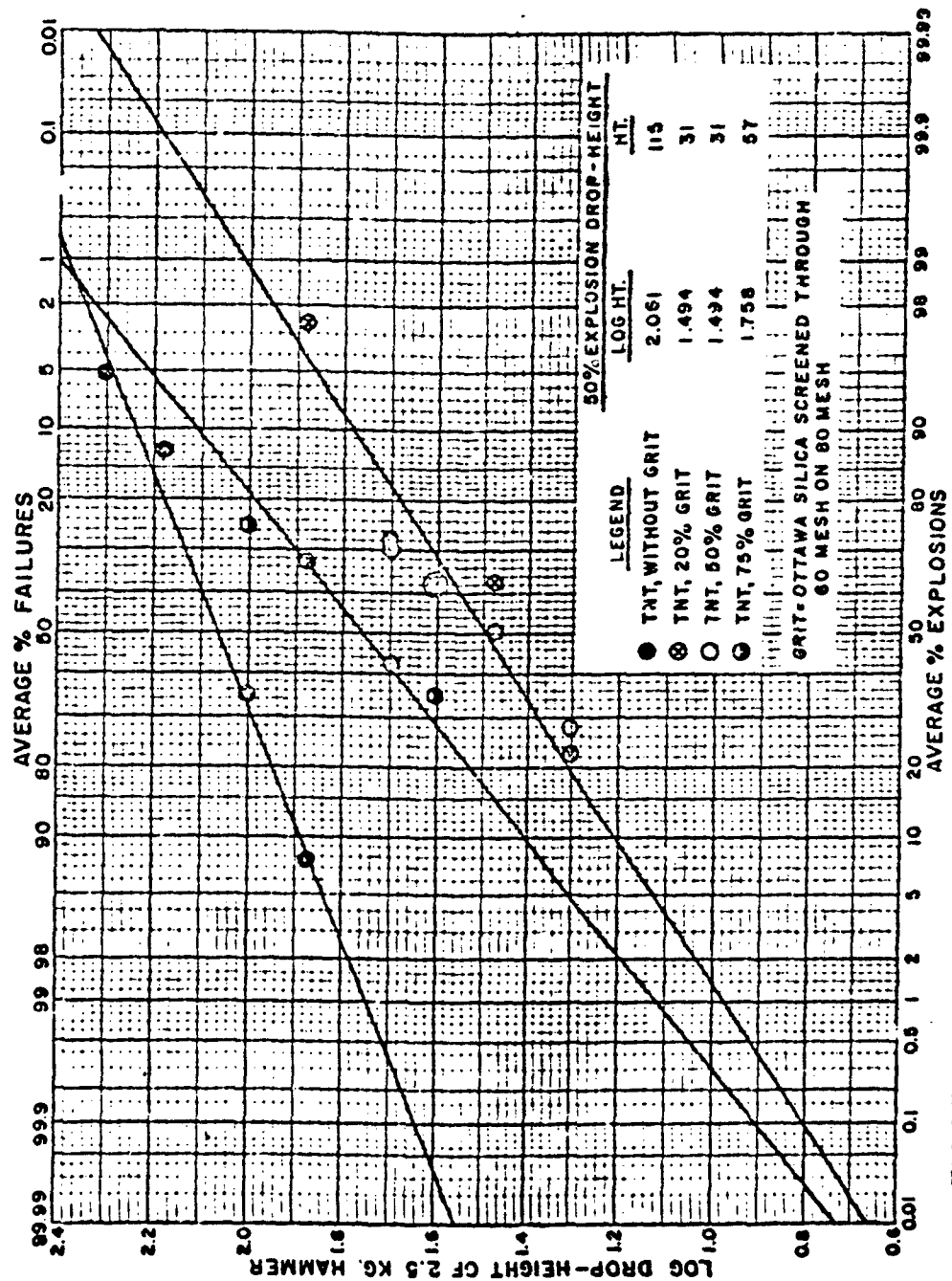


FIG.23 THE EFFECT OF ADDED GRIT ON THE SENSITIVITY OF TNT,
AS STUDIED BY DESIGN NO.12

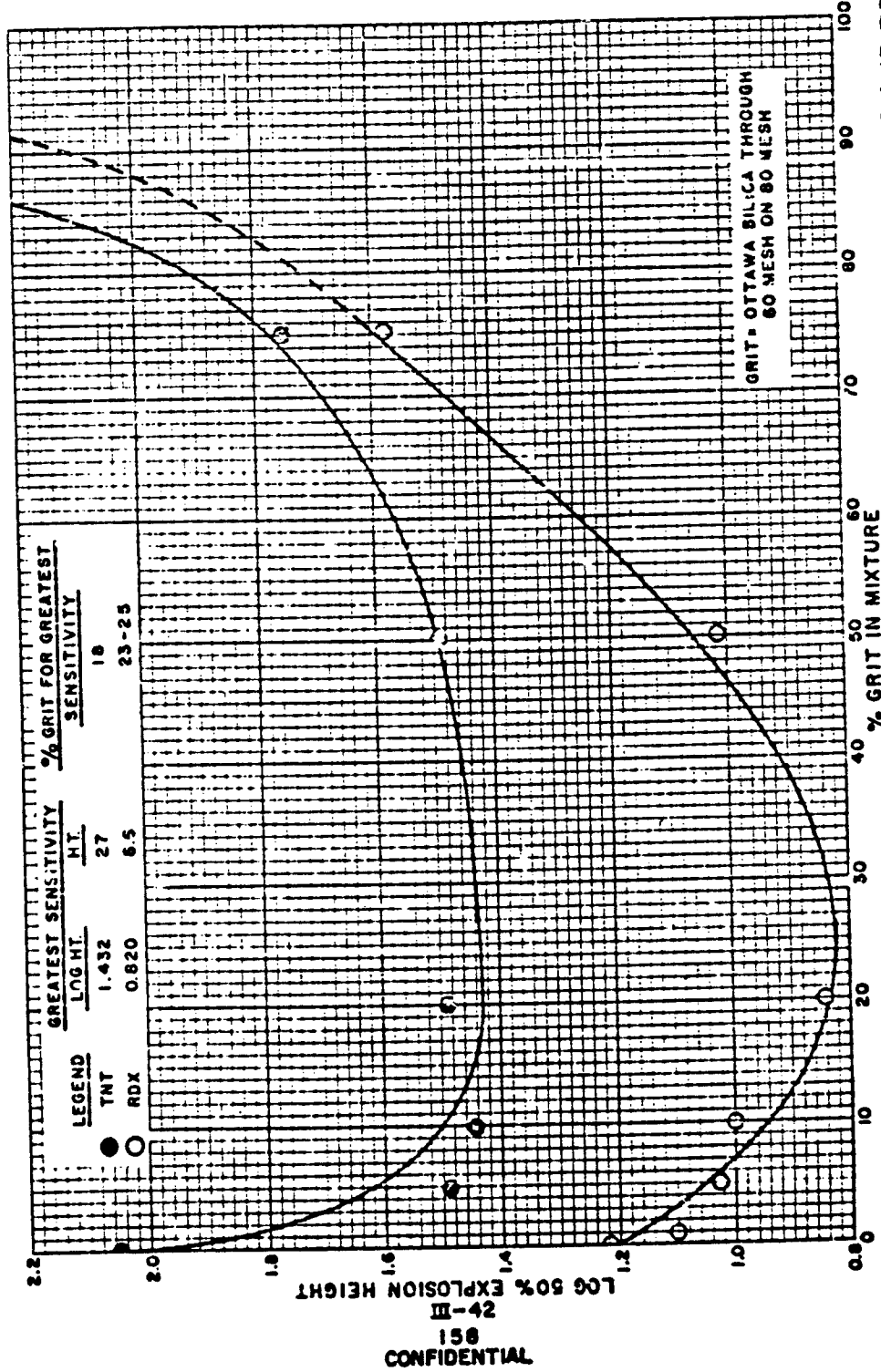


FIG.24 THE EFFECT OF ADDED GRIT ON THE 50% EXPLOSION HEIGHT OF TNT AND RDX,
AS TESTED BY DESIGN NO.12

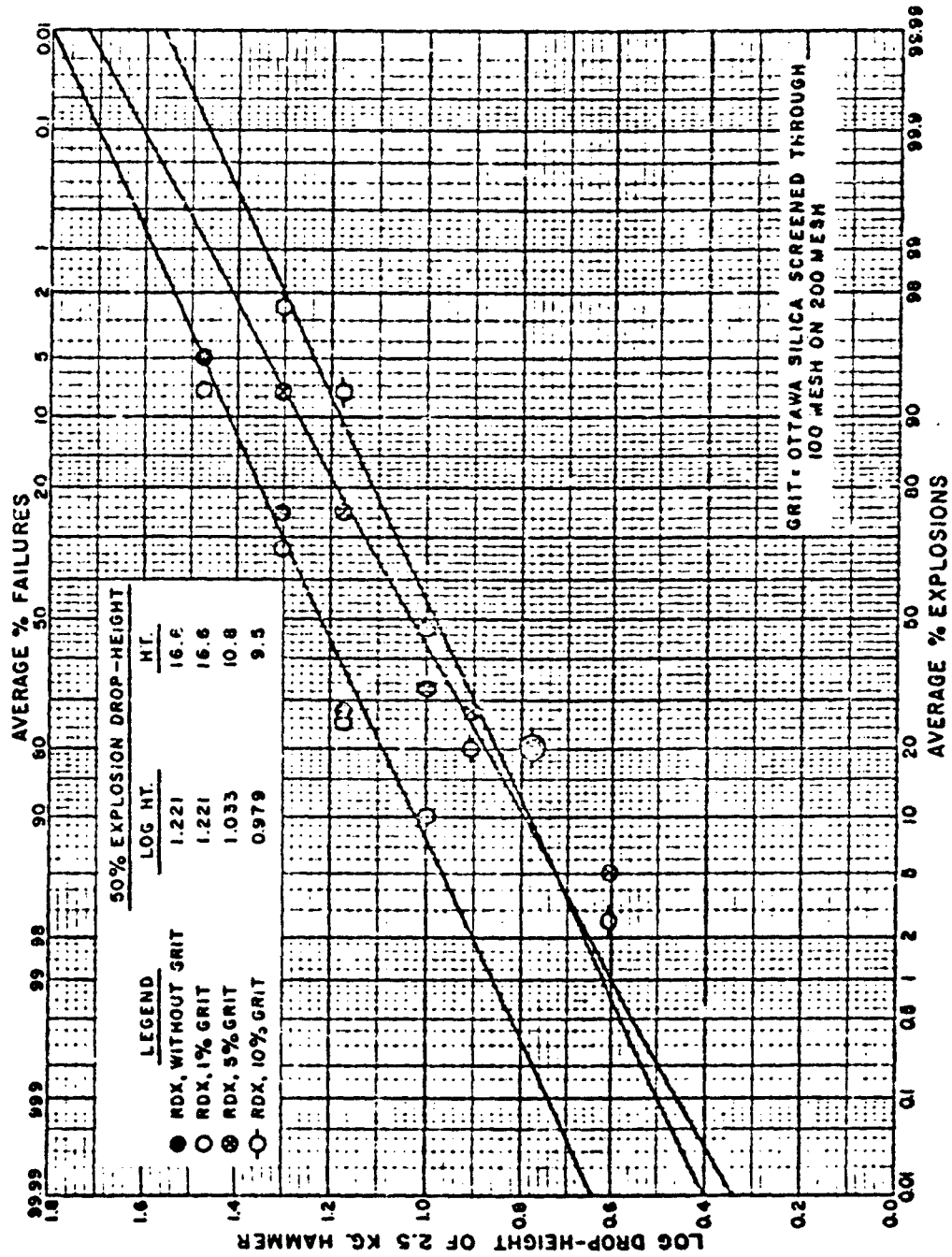


FIG. 25 THE EFFECT OF ADDED GRIT ON THE SENSITIVITY OF RDX,
AS STUDIED BY DESIGN NO. 12

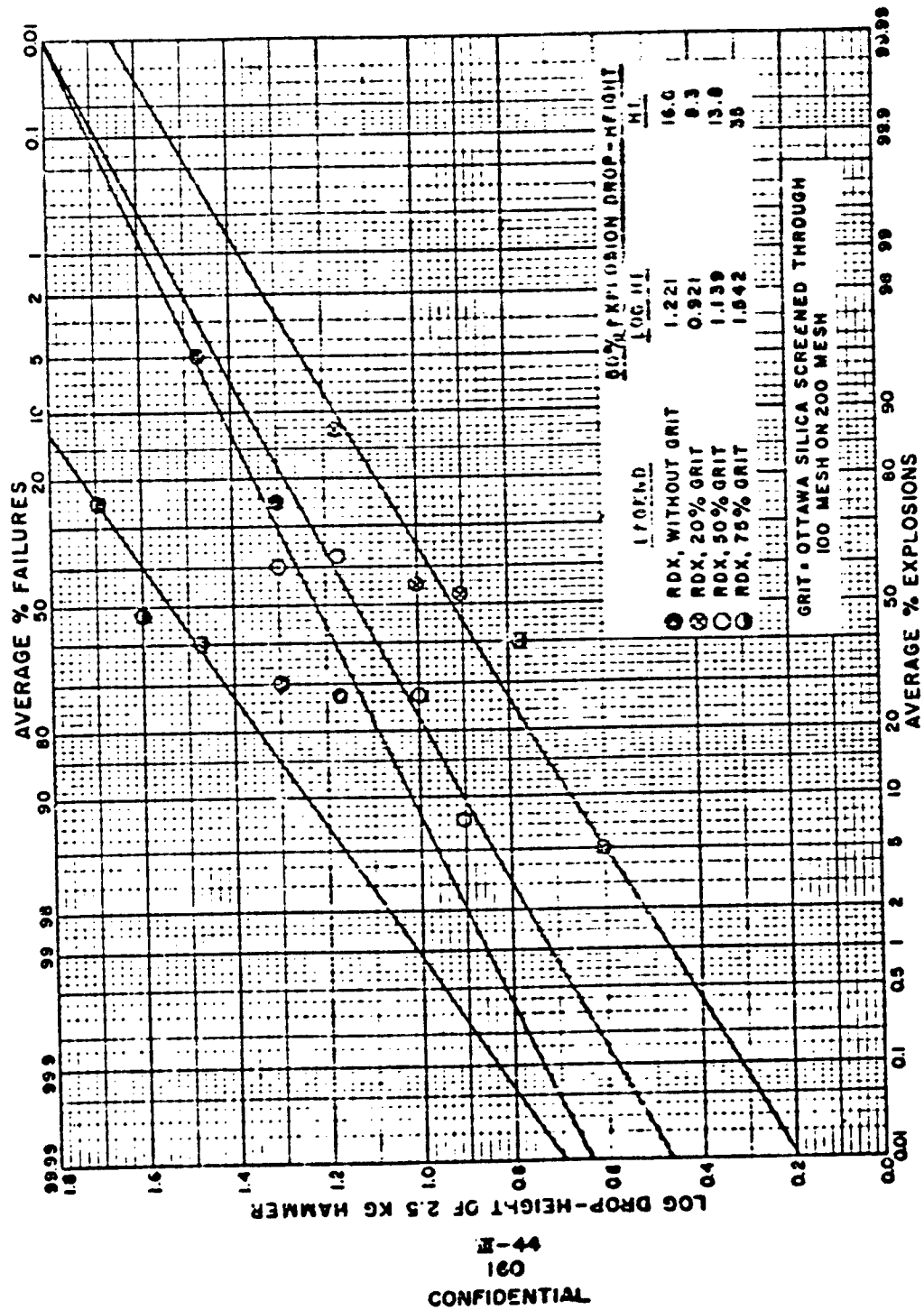
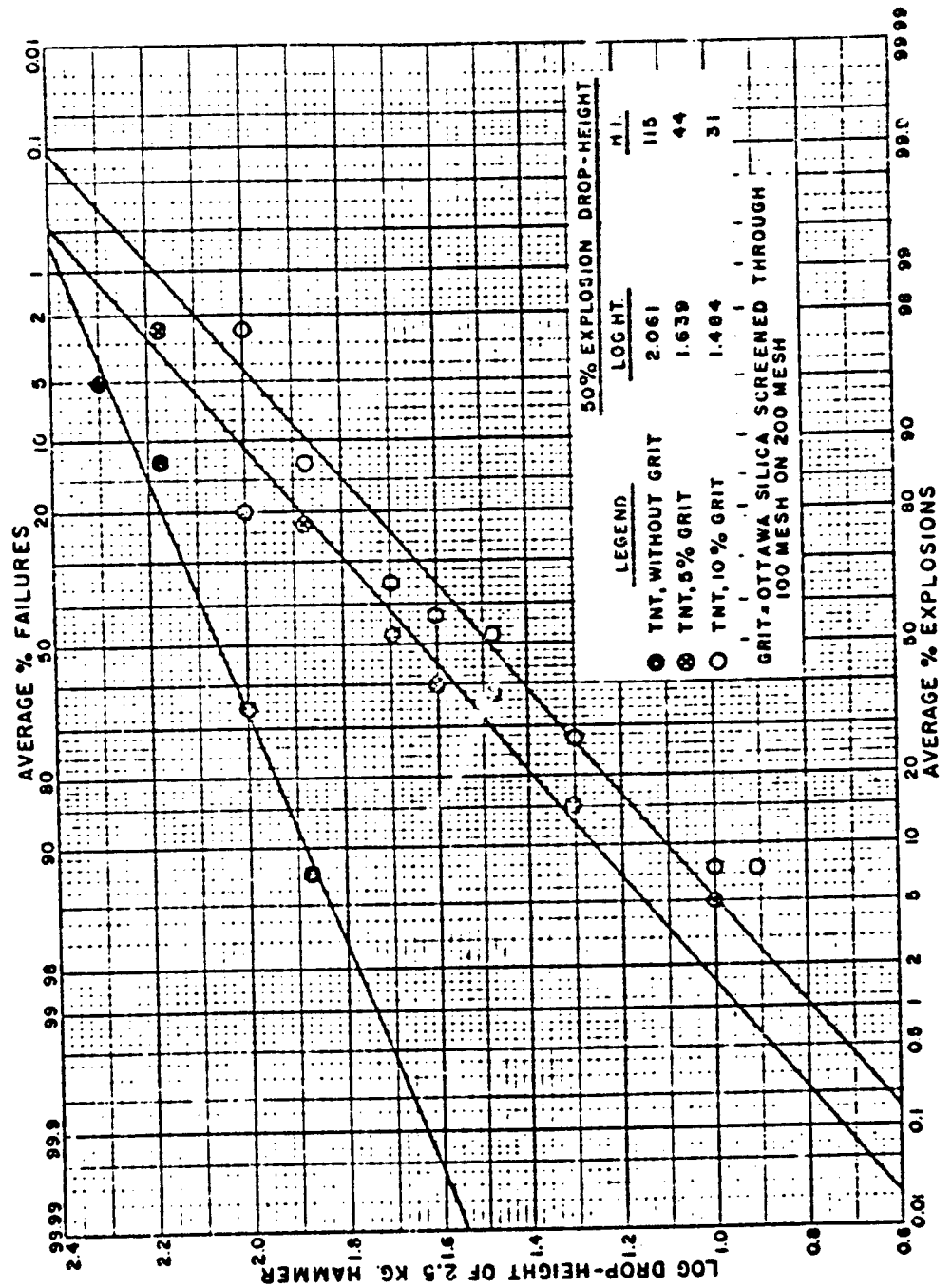


FIG.26 THE EFFECT OF ADDED GRIT ON THE SENSITIVITY OF RDX,
AS STUDIED BY DESIGN NO. 12



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FIG. 27 THE EFFECT OF ADDED GRIT ON THE SENSITIVITY OF TNT, AS STUDIED BY DESIGN NO. 12

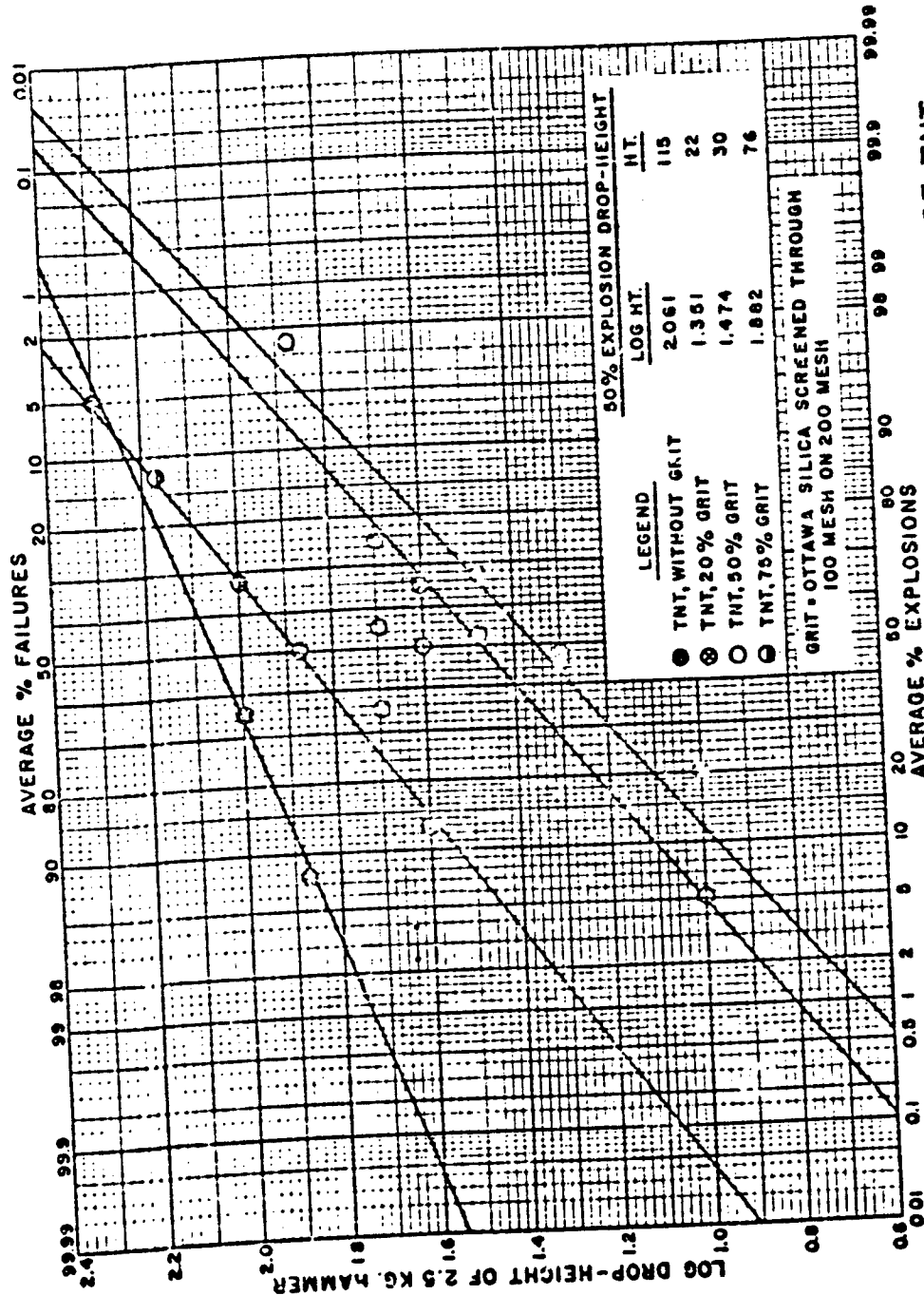


FIG. 28 THE EFFECT OF ADDED GRIT ON THE SENSITIVITY OF TNT,
AS STUDIED BY DESIGN NO. 12

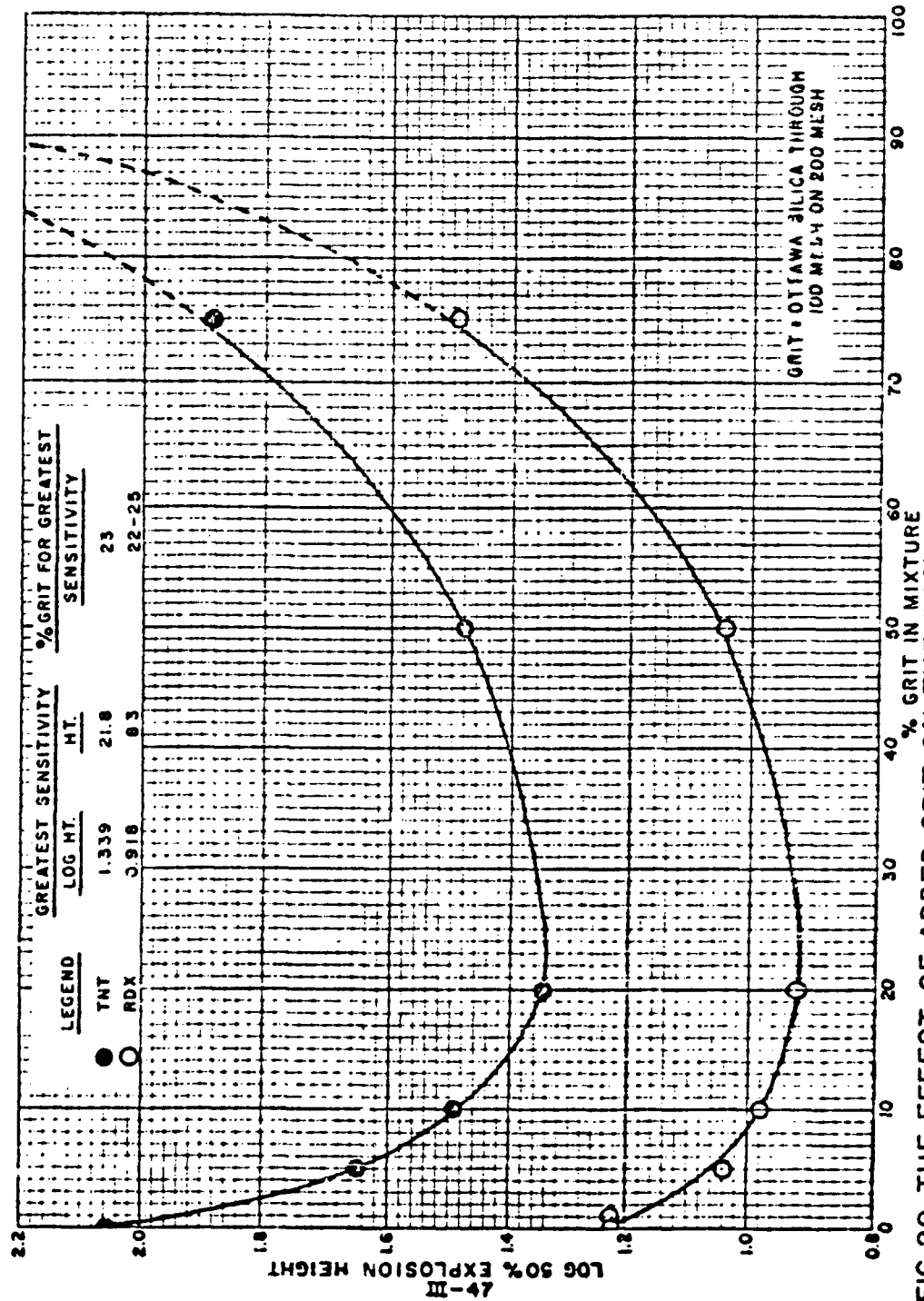


FIG.29 THE EFFECT OF ADDED GRIT ON THE 50% EXPLOSION HEIGHT OF TNT AND RDX, AS TESTED BY DESIGN NO.12

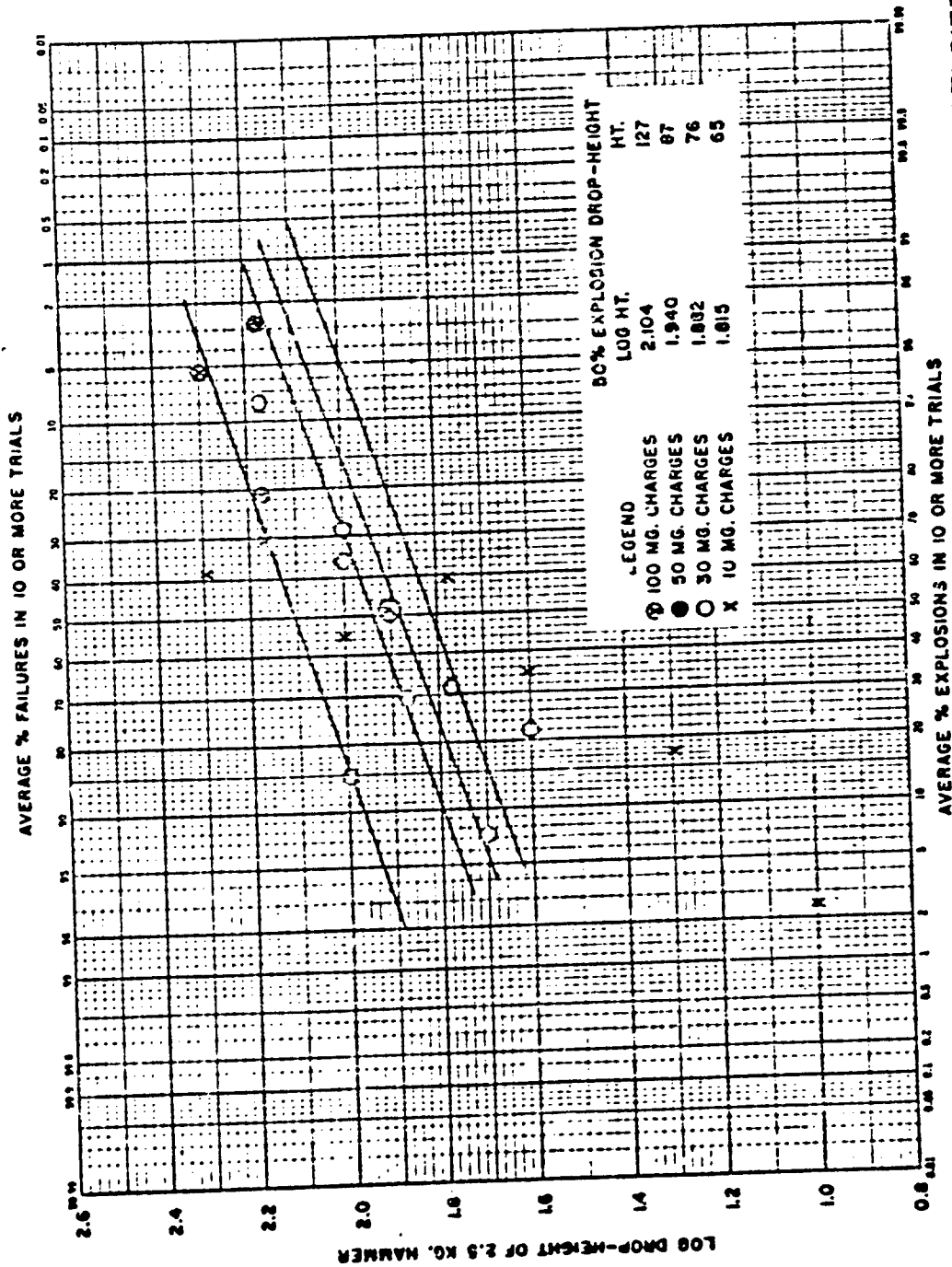


FIG. 30 COMPARATIVE SENSITIVITIES OF TNT CHARGES OF VARIED WEIGHT AS STUDIED BY DESIGN NO.12

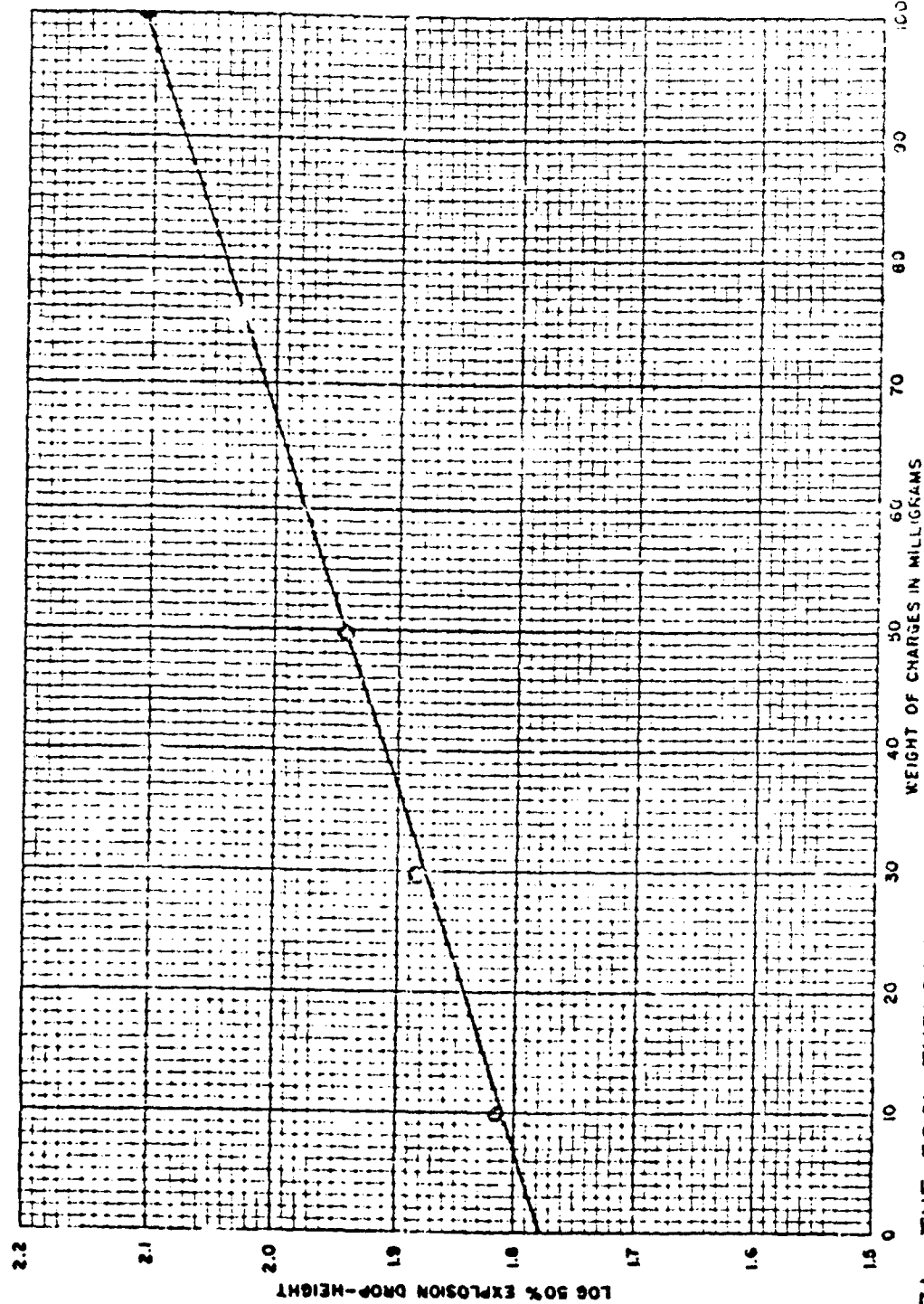
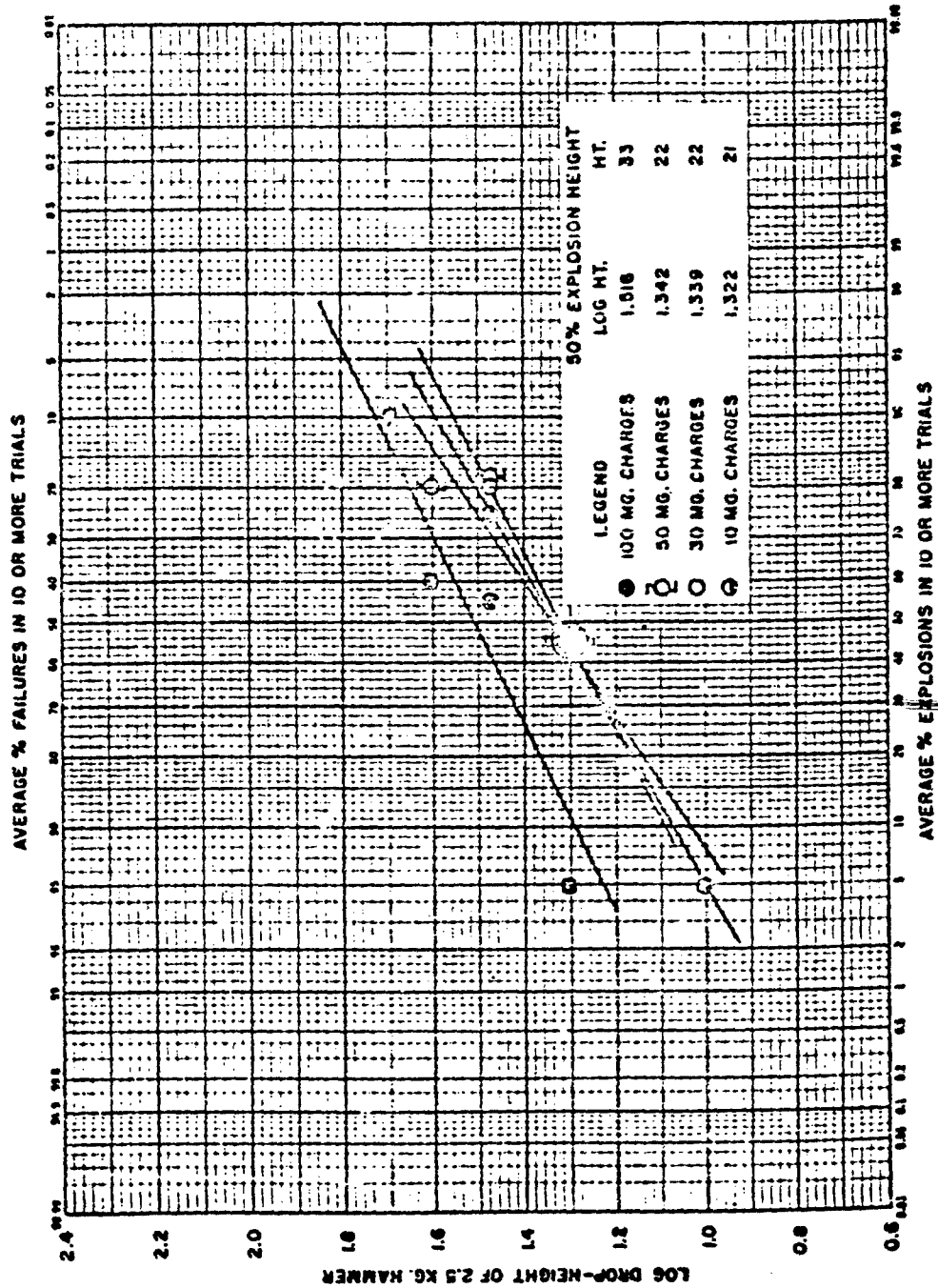
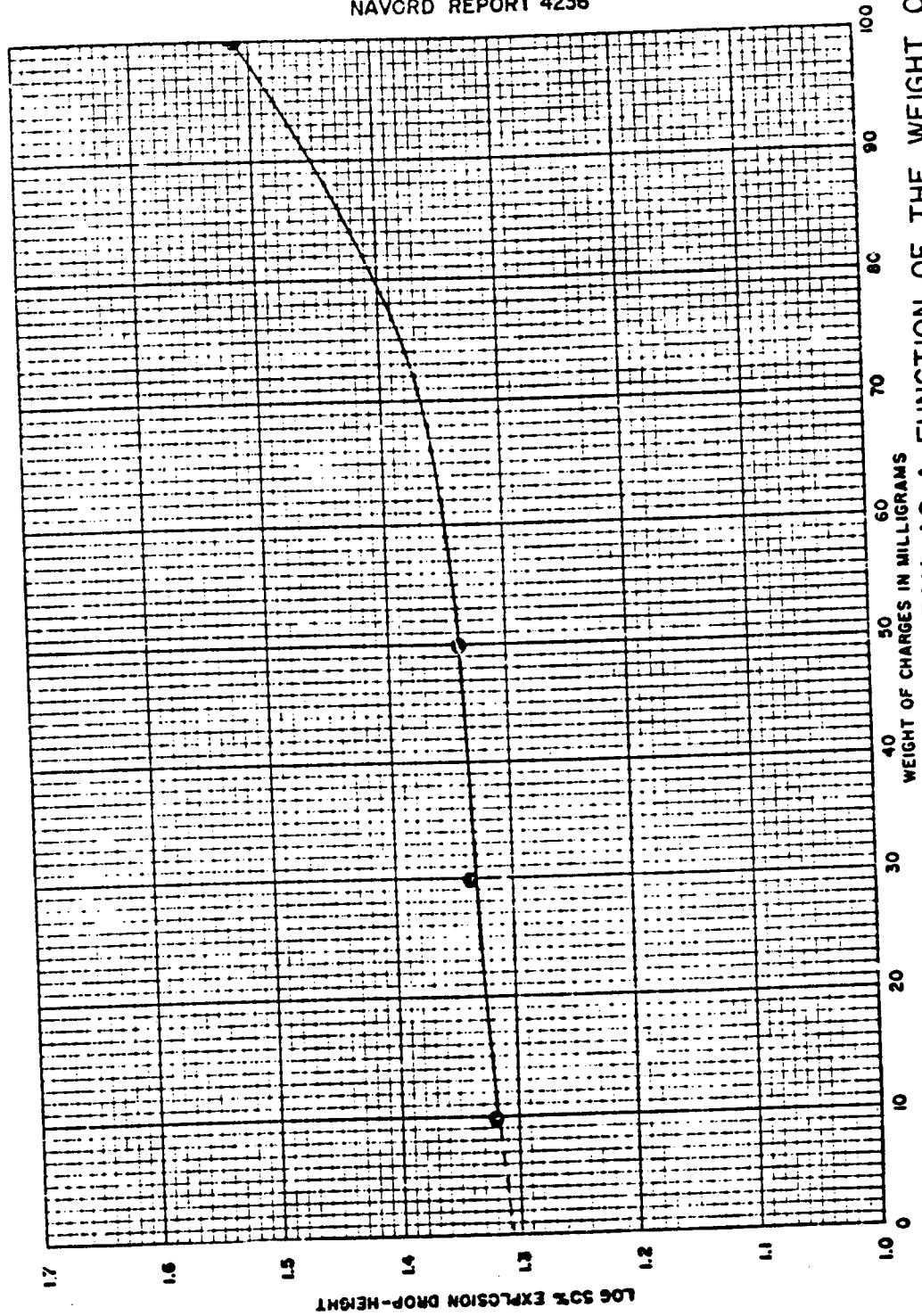


FIG. 31 THE 50% EXPLOSION DROP-HEIGHT OF TNT AS A FUNCTION OF THE WEIGHT OF MATERIAL TESTED BY DESIGN NO. 12



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FIG. 32 COMPARATIVE SENSITIVITIES OF RDX CHARGES OF VARIED WEIGHT AS STUDIED BY DESIGN NO. 12



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FIG. 33 THE 50% EXPLOSION DROP-HEIGHT OF RDX AS A FUNCTION OF THE WEIGHT OF MATERIAL TESTED BY DESIGN NO. 12

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- B. Developing Methods of Interpretating the Results of the Impact Sensitivity Test

EXPERIMENTAL RESULTS

- C. Developing a Sensitivity Test that Would Give Reproducible Results
- D. Developing an Impact Test that Gave Results in Agreement with Practice

CONCLUSIONS

- A. General Theory
- B. Recommendations

BIBLIOGRAPHY

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REPORT IV

Bruceton, Pa.
September 28, 1945

Report to: Dr. Eugene H. Eyster
From: Rogers F. Davis
Subject: Concluding Discussion of the Problem of
the Behavior of Explosives to Impact

Summary

This report serves to discuss a brief history of the impact sensitivity problem at Bruceton and conclusions reached after three years of developmental procedures. There are also discussed recommendations which may ease the difficulties to be encountered in future research on the problem.

Introductory Statements

A survey of developmental work on the impact problem at Bruceton was presented in two reports to Dr. E. H. Eyster (1). It is assumed that the reader is familiar with these reports in addition to OSRD Report No. 804 (2), and numerous OSRD Interim Reports in which impact sensitivity is discussed by Drs. MacDougall and Eyster.

History of the Problem

The general problem of the impact sensitivity of explosives is built around the general query of: from a practical viewpoint, how sensitive to impact are explosives of commercial and military possibilities? This may be expanded to include the safety aspects as far as manufacture, general handling around the manufacturing plant and in shipping, and the use that a particular explosive will be subjected to if it is to be adopted by the Armed Forces.

To answer these problems, the so-called impact sensitivity test has been developed in the course of the last 40 years (1). Unfortunately, there has also developed the general conception that a relatively simple impact test conducted on an explosive will reveal its military and commercial aspects from a safety point of view. This particular approach is false in that the overall safety evaluation of an explosive

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cannot be obtained through the medium of a small scale test which certainly does not reproduce all of the conditions of practice.

With the exception of bullet sensitivity tests, it is only during the past five years (3, 4, 5, 6) that the important idea of developing a particular test to reproduce field conditions has materialized.

In the final analysis, an impact machine can give an ordering in a comparative sense of the behavior of explosives to the particular impact test conducted. We have found that by varying the conditions (confinement mainly) that vastly different comparative sensitivities are obtained.

We quickly arrive at the general question as to why we have the sensitivity test. The real value of such a test is to obtain information concerning the comparative behavior of explosives to a test that has been conducted many times on many explosives. Such a test usually is the result of a period of development, and the comparative order of explosives by this test is known. Likewise, the impact test is developed along lines to give orders of sensitivity which are in reasonably good agreement with practice. For instance, from a practical viewpoint we would consider an impact test as misleading if we found that Mercury Fulminate were more insensitive than solid TNT or that Teteryl were more insensitive than Explosive D. We know the safety history of these substances from practice. Thus, if we can develop a small scale test that will give us a practical ordering of the sensitivity of explosives, we have a preliminary criterion to evaluate the safety of the material. This is indeed valuable in that long range developmental procedure on a given explosive will not be attempted if initial tests indicate that it would be unwise from a safety viewpoint.

Statement of the Problem

At Bruceton we have been confronted with four general aspects of the impact sensitivity problem:

- A. To develop a sensitivity test that would permit a definite comparative evaluation of all solid explosives.
- B. To develop methods of interpreting the results obtained.
- C. To develop a test that would give reproducible evaluations.

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D. To develop a sensitivity test that would agree with practice in its evaluations.

Experimental Procedure

A. Developing a sensitivity test that would permit a definite comparative evaluation of all solid explosives:

Impact on an explosive may be direct or indirect. For the problem at Bruceton, we have employed indirect impact, i.e., the small amount (35 mg.) of explosive is placed between two parallel metallic surfaces and struck indirectly by means of a falling body of known mass which hits the upper of the two parallel surfaces. The procedure involving indirect impact is advantageous in that the metallic surfaces are subjected to deformation from impacts and explosions, and frequently must be replaced; thus a simple piston-anvil arrangement permits a more careful control of surfaces. Too, hits are more reproducible by using indirect impact in that a falling body does not always follow the same downward path; but the deviation is minimized by having the weight striker a rigidly held piston (striker or plunger) - anvil combination.

Table I and Figures 1-7 summarize the important types of piston-anvil combinations which were developed over a period of three years at Bruceton.

The general conclusion regarding surfaces is that unless impact energy be concentrated over a reasonably small area of non-flowing explosive, the chances are that no or weak explosions will occur. From the surfaces discussed in Table I, we can see that the above principle is nearly achieved in only one design, namely that of resting the explosive upon abrasive materials.

B. Developing methods of interpreting the results of the impact sensitivity test.

A discussion of the so-called "Bruceton Up and Down" abbreviated and the conventional interpretation of results is to be found in OSRD Report No. 804 and in report to Dr. E.H. Eyster from this writer.

A newer statistical interpretation is discussed in the Applied Mathematics Panel Report of July, 1944 (7). This report treats statistical methods of calculating the height of fall to produce explosions with a probability of 0.01, 0.10, 0.50, and 0.90 from a minimum of 100 trials per explosive.

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TABLE I

SUMMARY OF IMPORTANT TYPES OF PISTON-ANVIL
COMBINATIONS DEVELOPED FOR THE IMPACT TEST AT BRUCETON

Nature of Surfaces	Design Number	Outline of Diagrammatic Principles	Advantages	Disadvantages
Flat Parallel	1	Refer to Fig. 1	<ol style="list-style-type: none"> 1. Simple to assemble and maintain. 2. A practical approach is that the test is analogous to a punching between two smooth surfaces as is sometimes seen in practice. 	<ol style="list-style-type: none"> 1. Explosive undergoes plastic flow and most of it escapes during impact, with not enough material remaining to produce an audible explosion. 2. Area of explosive is changing rapidly during the impact process. ΔA is high because of slippery metallic surfaces, and this distributes the impact energy over so great an area that a detonation does not occur with ease.
Curved Both piston and anvil are convex.	1.4	Refer to Fig. 2	<ol style="list-style-type: none"> 1. Permits the best practical concentration of energy, as contact area is nearly a point. 	<ol style="list-style-type: none"> 1. Contact area is too small and the amount of explosive receiving impact is not enough to produce an audible explosion. Nearly all of the explosive layer is forced away from the surface. 2. It is difficult to machine these surfaces and to maintain them constantly spherical.
Curved Piston: Convex Anvil: Concave	5	Refer to Fig. 3	<ol style="list-style-type: none"> 1. Placed TNT within the range of drop of the small impact machine (100-125 cm.) 	<ol style="list-style-type: none"> 1. Difficult to machine these surfaces and to keep them constantly spherical. 2. Soft, waxy substances escape most of the impact by squeezing out.
Flat Parallel Cylindrical Cavity in Anvil	5	Refer to Fig. 4	<ol style="list-style-type: none"> 1. Placed practically all solid explosive within range of drop height - no small impact machines. 2. Most explosions resulting are unquestionable loud and definite. 3. Permits very reproducible conditions. 	<ol style="list-style-type: none"> 1. Very difficult to maintain constant conditions. Vastly different results are obtained when clearance between piston and cavity wall exceeds 0.001". 2. Conditions for scale of sensitivity evaluations. 3. Gives orders of sensitivity which are not in agreement with practice.
Flat Parallel Explosive in Cups.	3	Refer to Fig. 5	<ol style="list-style-type: none"> 1. Surfaces are easy to machine and to keep constant. Make a new cup to test for each trial; conditions tend to remain constant over a longer period of time. 2. Results are in general reproducible. 3. An ideal method of testing sensitive and booster-type of explosives. 4. Presents a rapid means of obtaining observations. 	<ol style="list-style-type: none"> 1. Inertive materials cannot be exploded as height of fall of weight is limited to 100 cm. Piston tips bulge and crack from kinetic energies greater than 500 kg.-cm. 2. Brass cups bulge to permit much of explosive to escape impact by flowing into bulged areas and between walls of the cup and the piston tips, resulting in weak or no explosion for materials more insensitive than Tetryl. Most soft, waxy substances will not explode with these surfaces - had example to DINA.
Flat Parallel Explosive resting on abrasive paper placed between metallic surfaces.	11, 12	Refer to Fig. 6 for Design 11 and Fig. 7 for Design 12	<ol style="list-style-type: none"> 1. Permits a comparative evaluation of nearly all solid explosives. 2. Surfaces are nearly kept constant. A few square of abrasive paper is used for each test. 3. Surfaces are durable and require only occasional replacement. 4. The test is fairly reproducible over a period of time. The reproducibility for sensitivities of intermediate classes of substances is quite good. 	<ol style="list-style-type: none"> 1. Design 11 which used a piston of 1/2" diameter permitted most of the charges of insensitive materials to escape during impact from a body falling over 125 cm., and the ΔE remained about 60 as the height of fall was increased. Difficulty was solved by using a piston of 1 1/4" diameter. 2. The paper base of the abrasive paper reacts with oxygen rich compounds and lowers the practical evaluations. Abrasive coated metal may eliminate this difficulty. 3. Presence of abrasive will not permit a study of small amounts of added grit on sensitivity. The effect of the addition of grit less than 5% cannot be detected by this test. 4. These surfaces produce many "doubtful" explosions which present conditions for auditory interpretation.

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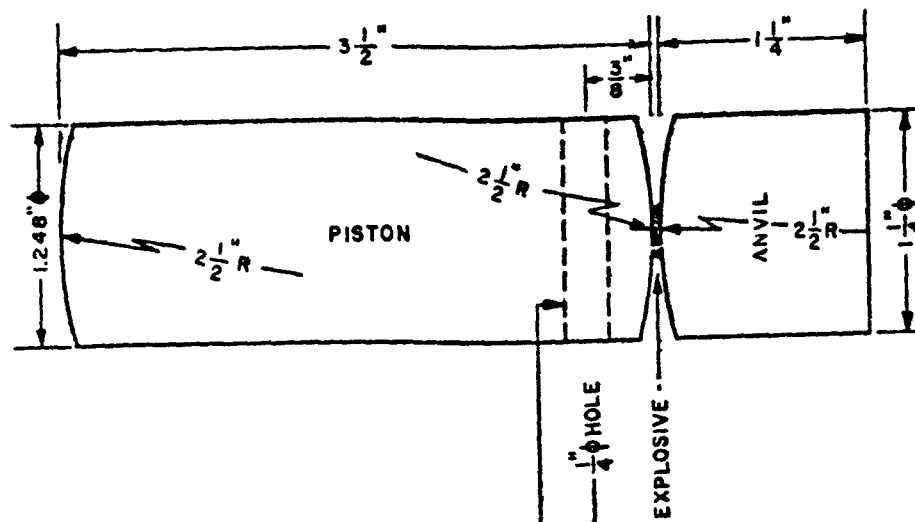


FIG. 2 DESIGN NO. 14

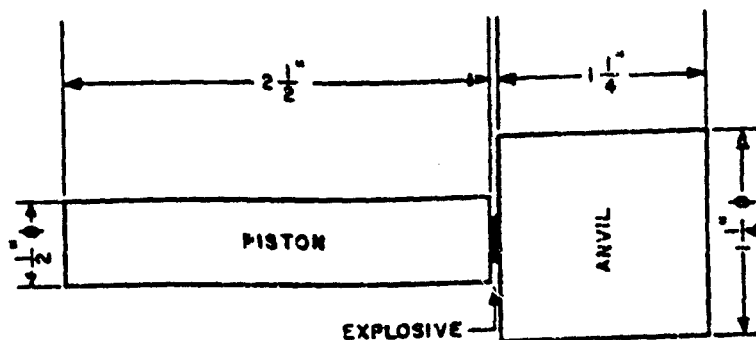


FIG. 1 DESIGN NO. 1

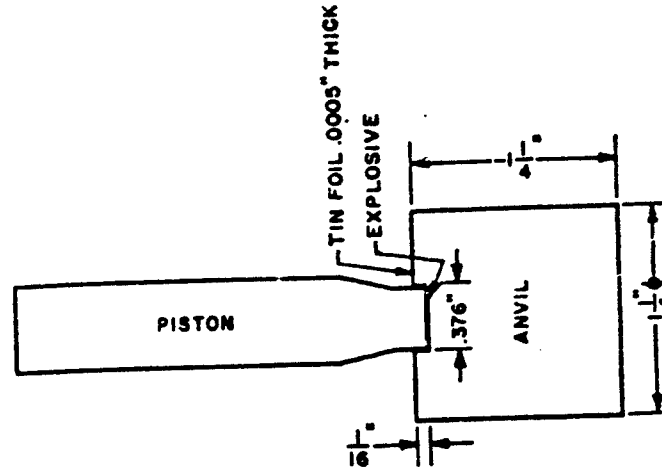
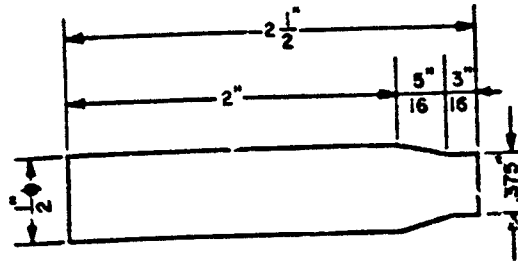


FIG. 4 DESIGN NO. 5

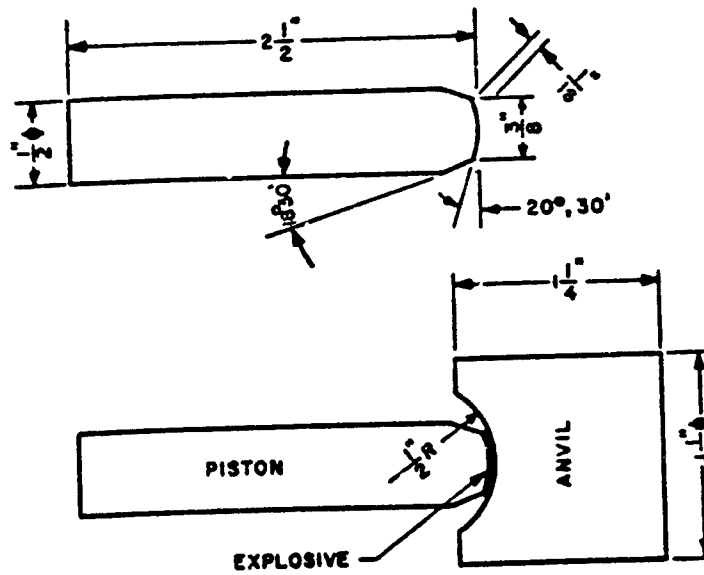


FIG. 3 DESIGN NO. 4

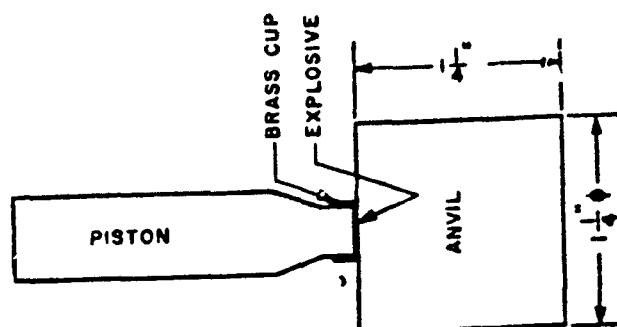
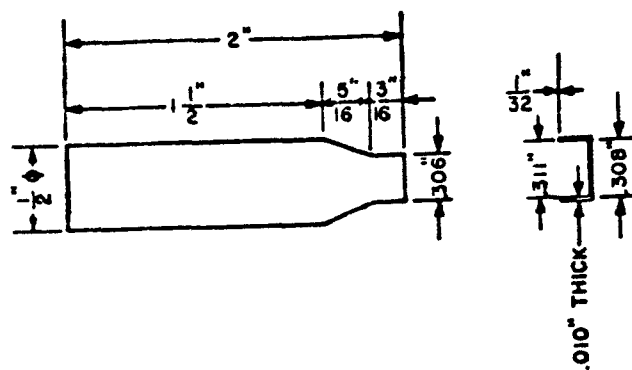


FIG. 5 DESIGN NO. 3

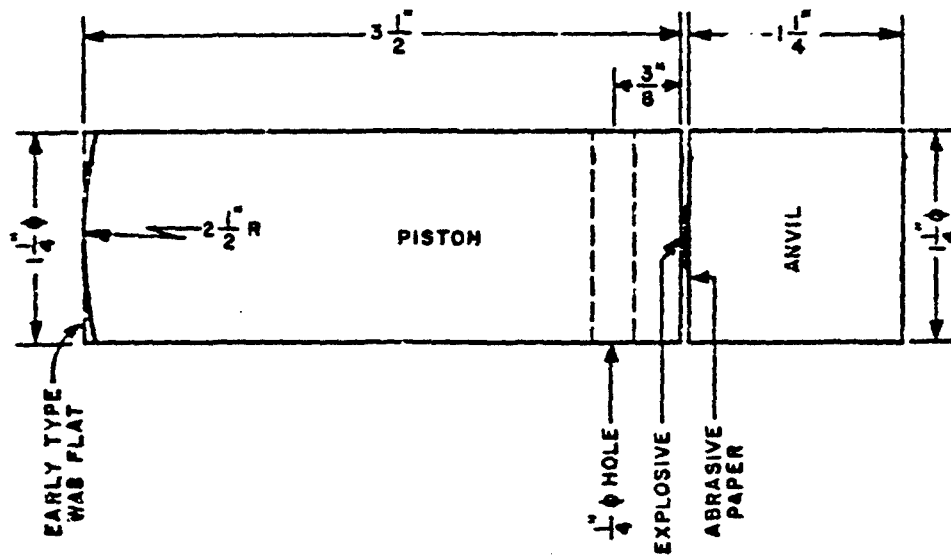


FIG. 7 DESIGN NO.12

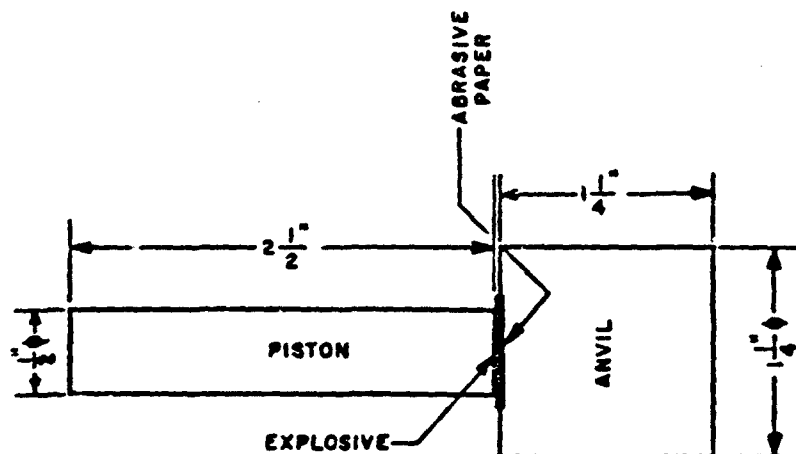


FIG. 6 DESIGN NO.11

Experimental Results

C. Developing a sensitivity test that would give reproducible results:

Obtaining reproducible results has been the most difficult phase of the impact problem at Bruceton.

The general conclusion is that some mechanical means of determining the extent of explosion from impact must be developed, instead of relying on personal judgement. This has been attempted by measuring the sound of explosion with a microphone-amplifier-oscilloscope set-up. Unfortunately not enough data were obtained to answer the question of reproducibility, as some eleven explosives were tested only once by the conventional scheme.

Recently an electrical trigger circuit has been connected in series with a microphone, amplifier, and oscilloscope. In the trigger circuit, a small neon light is actuated by the sound blast from an explosion. The trigger was calibrated to fail to light when the 2.5 Kg., drop-hammer fell 11 feet (maximum drop-height of present large impact machine) to strike a "blank explosive". In our case this was a "charge" of sodium chloride. Any louder sound would have actuated the light. The light is not correct in all cases, however, and the circuit needs the attention of an electrical engineer at the present time. Although the circuit is not perfect, the method of qualitatively interpreting results seems to be in the right direction. (Subsequently, work was done at the Naval Ordnance Laboratory on the neon light system. Final results are described in Appendix I of NAVORD Report 3592, "Factors Affecting the Behavior of Explosives to Mechanical Shock", G. Svadeba, 18 December 1953.)

A comparison of mean values of common explosive for the Type 12 impact machine may be seen in Table II. Tables III and IIIa show the kind of reproducibility in results obtained by personal judgement and also by the trigger circuit.

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TABLE II

COMPARISON OF OBSERVER AND MECHANICAL LIGHT FOR MEAN
VALUES OF 50-TRIAL "UP AND DOWN" RUNS FROM TYPE 12
IMPACT TEST. (Numbers in Parentheses Indicate Number of
Runs to Obtain Listed Mean Value.)

Common Name of Explosive	Observer (J. M.)		Light	
	Mean(cm.)	TNT=100	Mean(cm.)	TNT=100
PETN	12 (4)	7	10 (1)	7
RDX	19 (7)	12	19 (1)	13
DINA	22 (1)	13	25 (2)	17
*Tetryl	41 (5)	25	41 (1)	27
*Pentolite	42 (6)	26	28 (1)	19
EDNA	42 (2)	26	28 (1)	19
*Torpex, Unwaxed	50 (3)	30	88 (1)	59
*Minol-2	60 (3)	37	30 (1)	20
*75/25 Tetrytol	67 (1)	41	103 (1)	69
*Composition A	72 (5)	44	75 (3)	50
*55/45 Ednatol	74 (2)	45	87 (1)	58
*Fivonite	74 (1)	45	90 (1)	60
*Composition B	82 (10)	50	70 (3)	47
*Torpex-2, Waxed	83 (17)	51	86 (1)	57
*HBX, Paraffin	116 (3)	71	140 (1)	93
*Torpex D-1, Paraffin	136 (16)	83	209 (1)	90 ^x
*UWE	141 (9)	86	207 (1)	90 ^x
*TNT	164 (10)	100	150(13), 231 (1)**	100
Explosive D	255 (1)	155	272 (1)	118 ^x
*50/50 Amatol			33 (1)	22

^xTNT = 231 cm. Others, TNT = 150

*Material screened 50% through 16 on 30 mesh and 50% through 30 on 50 mesh.

**Value obtained on day Torpex D-1, UWE, and Explosive D were tested.

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TABLE III

DATA SHOWING REPRODUCIBILITY OF RESULTS OBTAINED BY
PERSONAL JUDGEMENT FROM THE TYPE 12 IMPACT TEST
INVOLVING 50 TRIAL "UP AND DOWN" RUNS

Explosive	Mean Values (Rounded)
PETN	10.5, 13, 13, 12
RDX	18, 15, 15, 18.5, 23, 21, 24
Tetryl	39, 33, 42, 53, 40
Pentolite	44, 39, 44, 44, 38, 41
EDNA	40, 44
Torpex, Unwaxed	46, 57, 46
60/40 Cyclotol	55, 66
DBX	52, 75
Composition A	69, 75, 69, 75, 71
55/45 Ednatol	71, 77
Composition B	86, 65, 76, 72, 74, 68, 82, 64, 116, 114, 81
Torpex, Waxed	81, 86, 81, 85, 82, 107, 90, 83, 60, 62.5, 72, 85, 69, 99, 96, 85, 91
HBX, Paraffin	107, 121, 120
HBX, Stanolind	141, 120, 132, 113, 127, 123, 125, 107
Torpex D-1, Paraffin	152, 130, 132, 136, 134, 134, 126.5, 100, 107, 212, 109, 145, 142, 134, 118, 99
UWE	102, 105, 118, 121, 132, 169, 203, 167, 149
Minol	65, 68, 47
TNT	130, 145, 171, 146, 161, 123, 138, 141, 165, 156, 153, 176, 207, 253, 189

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TABLE IIIa

DATA SHOWING REPRODUCIBILITY OF RESULTS OBTAINED BY
TRIGGER CIRCUIT FROM THE TYPE 12 IMPACT TEST
INVOLVING 50 TRIAL "UP AND DOWN" RUNS

Explosive	Mean Values (Rounded)
Composition B	70, 64, 77
Composition B-2	71, 70, 71.5
Composition A	68, 73, 83
DINA	24, 25
TNT	130, 134, 125, 134, 132, 143, 140, 173, 130, 155, 182, 197, 231 (arranged chronologically)

The above values were obtained by using the neon light as the criterion for an "up" or "down" in height during the actual runs. On the day the value of 231 cm. for TNT was obtained, the light was checked against the oscilloscope by photographing the traces; and it was found that the light was incorrect. Deflections of maximum rise on the trace were as great as 5.6 mm. for TNT and yet registered as N by the light. Past experience has indicated that deflections greater than 3.0 mm. are nearly always an indication of an explosion.

Below are shown data from the actual run which illustrates the error of the neon light interpretation. The explosive is TNT and the mean for the run was calculated to be 230.8 cm. The observer is seen to be correct most of the time.

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Height	Light	Observer	Deflection	H	L	O	D
75	N	E _p	4.9	212	E	E ₁	2.7
106	N	E _p	5.8	150	N	N	5.0
150	N	N	1.2	212	N	N	2.1
212	E	E ₁	7.9	300	N	D	5.0
150	N	N	1.7	(424)	(E)	(E)	---
212	N	D	3.1	300	E	E	7.0
300	E	E	6.3	212	N	D	3.4
212	N	D	4.8	300	E	E _p	5.8
300	N	E _p	4.7	212	N	N	2.0
(424)	(E)	(E)	---	300	E	E ₁	8.3
300	E	E ₁	6.2	212	N	E _p	5.1
212	E	E	7.3	300	E	E _p	6.0
150	N	N	1.6	212	N	D	4.5
212	N	N	1.6	300	N	E _p	5.0
300	E	D	4.0	(424)	(E)	(E)	---
212	E	E	6.6	300	E	E	6.0
150	E	E	6.4	212	E	E	8.0
106	N	N	1.2	150	N	N	0.8
150	N	E _p	4.1	212	N	N	2.3
212	E	N _p	3.9	300	E	E	5.8
150	N	N	1.1	212	E	E ₁	7.1
212	N	N	1.2	150	N	N	1.4
300	E	E ₁	7.0	212	N	D	4.1
212	N	N	1.0	300	E	E	5.9
				212	N	N	1.1
300	E	E	6.0	300	N	D	3.0

Once the electrical abnormality of the trigger circuit is corrected, one may undoubtedly expect better reproducibility. At this writing the light has not been corrected because of the absence from this laboratory of the designers of the circuit, Mr. Axlerod and Mr. Kollar.

It may likewise be an aid to obtaining better reproducibility among results to use small explosive pellets of initially constant dimensions instead of testing random shaped heaps of explosive for the impact "charge". Also, by measuring the gas evolved during explosion in a closed impact system, or by measuring the blast pressure evolved during explosion from impact may render results which are in better agreement.

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D. Developing an impact test which gave results in agreement with practice.

This has not been realized in an overall sense with any design yet developed at Bruceton. The Type 12 impact machine comes nearest to giving an ordering of sensitivities which is in agreement with practice. The deviations for this particular design appear with oxygen-rich substances, in which the sensitivity evaluations appear too high (more sensitive than expected).

We have verification (1) that oxygen-rich substances react with the paper base of the flint paper, and are thereby sensitized. This is especially true of $KClO_3$, NH_4ClO_4 , NH_4NO_3 and mixtures containing NH_4NO_3 such as Amatol, Minol, and DBX.

An approach to eliminating this difficulty was suggested sometime ago by Dr. MacDougall, in that abrasive coated metal disks should be substituted for the flint paper. This was attempted, but the disks appeared to have too fine an abrasive coating and the explosive flowed during impact as with smooth surfaces. Disks coated with coarser abrasive should eliminate this difficulty.

Conclusions

A. General Theory

It is a general statement that an explosion occurs when the heat supplied is greater than the heat removed in a given reaction. This likewise infers that an explosion occurs when the rate of heat application exceeds the rate of heat removal (8).

In the impact test:

Heat may be applied by:

- a. A resistance to rapid compression.
- b. Frictional phenomena.
- c. Adiabatic compression of air entrapped around crystals.

Heat may be removed by:

- a. Conduction.
- b. Radiation.
- c. Convection.

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Whether or not a substance undergoes rapid compression will depend upon its hardness. Soft crystals will offer less resistance to rapid compression, as their plastic flow pressure will be low. These substances will permit the impact energy to be concentrated over a greater area than for a hard substance. This property will in turn minimize frictional effects, the adiabatic compression of entrapped air (it should flow outward with the flowing of the solid), and as a result explosions from impact should be low in frequency and of a low order in intensity.

A hard crystal, on the other hand, will tend to resist rapid compression as its ability to flow is practically non-existent. Hard substances are always brittle and possess an exceedingly great or an indeterminate plastic flow pressure, as they usually fracture under great pressures. This property will permit the impact energy to be concentrated over a small area, and as a result explosions should be high in frequency and of greater violence than the case of soft, semi-plastic explosives.

Can we then say that, in general, hard explosive crystals are sensitive to impact while soft crystals are insensitive? The answer is affirmative in most cases, but exceptions do occur. This is best seen in Table IV which roughly compares some common explosives as to hardness and sensitivity.

The exceptions seen in Table IV, notably Nitromannite and Lead Azide, indicate that a factor other than hardness is involved in estimating impact sensitivities. This factor is most likely the thermal activation energy of the explosive. Thermal activation energies for several explosives were determined by Henkin (9) for gradual application of heat. In the impact process the heat is most likely applied over a period of time of the order of 10^{-6} to 10^{-4} sec. The values of and comparative orders of thermal activation energies for heat applied in this interval of time may not necessarily be comparable with those measured by Henkin, but his data are worth considering.

Henkin immersed a copper vial containing about 25 mg. of explosive into a molten alloy both of known temperatures, and measured the time for explosion to occur. Naturally, it required a finite time to apply heat to the explosive. The lowest explosion time Henkin measured was about 0.07 sec. In our case, the impact process has undergone completion in 0.07 sec.

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TABLE IV

A ROUGH COMPARISON OF SOME COMMON EXPLOSIVES AS
TO HARDNESS AND IMPACT SENSITIVITY

Explosive	Comparative Hardness*			Comparative Impact Sensitivity					
	Design 3			Design 12					
	H.	I.	L.	H.	I.	L.	H.	I.	L.
Lead Styphnate		?		X					
Nitromannite			X	X			X		
Lead Azide			X	X			X		
PETN	X			X			X		
RDX	X				X		X		
DINA			X			X			X
NENO			X		X				X
EDNA			X			X			X
Tetryl			X		X				X
Pentolite		X			X				X
Fivonite			X			X			X
Composition B			X			X			X
Picric Acid	X					X		X	
Emmet			X			X		X	
Composition A			X			X			X
TNT			X			X			X
Explosive D		X			X				X

	<u>Hardness</u>	<u>Sensitivity</u>
H = High	= Hard	Sensitive
I = Intermediate	= -	
L = Low	= Soft	Insensitive

*By personal judgement and estimation from experience in handling these substances.

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Henkin plotted $\log_{10} t$ (time or induction period) as a function of the reciprocal of the Absolute temperature, and obtained a linear relationship over most temperature ranges studied. The slope of the straight line determines the thermal activation energy from the well-known equation:

$$\log_{10} t = \frac{E}{2.303R} \frac{1}{T} + \text{constant}$$

where t is the length of the induction period
 R is the gas constant, expressed in calories
 T is the absolute temperature
 E is the thermal activation energy,
 expressed in calories

Shown below is a comparison of Henkin values of E (9) with rough evaluations of hardness and impact sensitivity.

Explosive	E(Calories)	Comparative Hardness			Comparative Impact Sensitivity		
		H.	I.	L.	H.	I.	L.
Lead Styphnate	58,800		?		X		
PETN	22,000	X			X		
DINA	12,000			X		X	(X)
NENO	17,200			X		X	
EDNA	10,000			X		X	(X)
Tetryl	14,400			X		X	
Fivonite	13,500			X		X	(X)
Emmet	15,000			X		X	(X)
Picric Acid	27,400	X				X	(X)

(X) Type 3 Impact Machine

Soft materials with low activation energies are: Fivonite, Tetryl, DINA, EDNA, NENO, and Emmet. These appear generally in the intermediate class of sensitivity. Their low activation energies may tend to shift them from the insensitive class of explosives, as the

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latter would be expected on the basis of their softness. However, under high confinement where their flow cannot counteract the low activation energy, these substances appear as relatively sensitive substances. This is seen in previously reported data (1) from the Type 5 impact machine.

These substances likewise appear insensitive under impact conditions where they may flow relatively freely. This is seen in data from the Type 1 and Type 3 impact tests (1).

The notable exception of high activation energy and high sensitivity seems to be Lead Styphnate, but its comparative hardness is questionable. The high value of E may explain why this substance explodes with greater violence than most other explosives. Once it becomes activated, the decomposition is most violent and complete in nature. The presence of the heavy lead atom may explain the exception in that appreciable internal strain is undoubtedly present within the molecule. This may also be true in the cases of sensitive Mercury Fulminate and Lead Azide, where again heavy metal atoms are held by comparatively weak linkage.

Another chemical factor which may determine sensitivity to a certain degree is the heat of explosion. Explosives with the higher heat of explosion may tend to be more sensitive, in that a group of molecules activated to explosion will activate neighboring molecules by the heat of explosion and propagation occurs. This property may account for the different propagation properties among explosives.

Theoretical heats of explosion of some explosives have been calculated by Brinkley and Wilson (10) and are correlated fairly well with impact sensitivity, as seen below.

Material	Heat of Explosion K cal. /Kg. (25°C)	Comparative	
		Impact Sensi- tivity	Propaga- tion
PETN	1410	High	Good
RDX	1240	"	"
NENO	1211	Intermediate	"
EDNA	981	"	"
Tetryl	890	"	"
MNO	736	Low	Fair
TNT	650	"	"

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These three properties of an explosive, namely, the comparative hardness, the thermal activation energy, and the heat of explosion seem to give a reasonably good preliminary estimate of the sensitivity class of the explosive. Heavy metal salts seem to be the only outstanding exception here.

It seems logical to assert that future research directed to the measurement or calculation of these properties may reveal important information.

General correlation of sensitivity with available heats of explosion⁽¹⁰⁾, thermal activation energies (9), and comparative hardness may be seen below. Comparative hardness could possibly be determined by measuring the velocity of sound in the explosive, as this represents the speed of the compression wave through the material. Materials in which the velocity of sound is low are soft, while hard substances permit sound to travel through them with greater velocities (11). Jones (12) has recently developed a method for measuring the velocity of sound in explosives, but his data are restricted to mixtures and only one (TNT) of the above pure substances.

Explosive	Comparative Sensitivity			Comparative Hardness			Heat of Explosion K cal. /Kg.	Thermal Activation Energy Calories
	H.	I.	L.	H.	I.	L.		
PETN	X			X			1410	22,000
RDX	X			X			1240	-----
NENO		X				X	1211	17,200
EDNA		X				X	981	10,000
Tetryl		X				X	890	14,400
MNO			X			X	736	-----
TNT			X			X	650	-----

B. Recommendations for Future Development

(a) A Type 12 impact machine should be developed in which the abrasive paper is replaced with an abrasive coated steel disk of about 1" diameter and 1/32" thickness. (Glass cloth has been used at the NOL

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but it is hard on the operator; see NAVORD Report 3592.)

(b) A closed system employing a design as discussed under (1) above should be developed to measure the blast pressure during an explosion from impact.

(c) The explosive charge should be either a small casting or pellet, cylindrical in shape and of constant initial dimensions. Pellets or castings of 0.065-0.075" in height and 0.25" diameter would be adequate. The random shapes and contact areas of an initial scoop or heap of explosive would be greatly minimized, should pellets be adopted.

(d) The striking surface of the falling weight should be curved instead of flat. If mechanically possible, a hardened steel sphere which could be rotated after each impact would be ideal in that repeated impacts would not be occurring over the same area to soon cause a deformation of the curved surface.

(e) 1. The base of the piston-anvil holder should be circular instead of square and should be made rigid by at least four instead of the usual two cap screws. Lock washers should also be used with these cap screws.

2. The piston-anvil holder should be one piece of equipment instead of a two piece holder, as are present holders.

3. A press fitted hardened steel insert should rest directly under the anvil to eliminate deformation of this area, which occurs with cold rolled steel.

4. The only interchangeable part of the piston-anvil holder should be the means of holding the anvil rigid and the piston guide ring (press fitted). The present arrangement seems adequate here.

(f) A revised Type 3 impact test could be developed in which the 0.306" diameter striker or piston tips are changed to 0.500" diameter, and the brass cups are replaced by hardened steel cups of about the same depth as current brass cups but of about 0.502" i.d. The cup material is important in that if it flows during impact, it permits creepage of the explosive and in turn enables the explosive to escape much of the impact energy. Hardened steel cups should not flow appreciably and explosions of greater frequency and violence may be obtained with insensitive

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materials. Too, the 1/2" diameter piston would be durable for impact energies greater than 500 Kg.-cm.

(g) If the intensity of sound is continued to be used as a criterion of explosion, the tests should be conducted in a constant humidity and temperature room.

(h) Dr. K. W. Tuckey of the AMP at Princeton University, Princeton, New Jersey recently visited us and has suggested that the interior walls of the firing chamber of the impact machine be covered with a sound absorbing material to eliminate possible echo effects, deflections of the sound waves, and perhaps guide the compression wave directly to the microphone. (This procedure is in use at the Naval Ordnance Laboratory.)

(i) Fundamental studies with impact are needed:

1. Investigation of the theories of Hertz (13) and St. Venant (14) should be undertaken to verify or discredit them as the case may be.

2. Contact times between bodies represented by the surfaces, velocities, and masses of the present impact test should be measured.

3. The impact pressures involved in the impact test should be known. These could be measured with a large, strongly built condenser gauge.

(j) An impact machine should be developed in which velocities 25 ft./sec. could be obtained. A compressed air-driven drop-hammer could easily approach velocities encountered in bomb dropping tests and most likely those attained in rifle bullet tests.

(k) More work should be directed towards the development of specific tests to answer a specific impact problem.

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Other Reports Which Include Recent Impact Sensitivity Work at the
Naval Ordnance Laboratory, White Oak,
Silver Spring, Maryland

The following list of reports contains sensitivity data obtained at the Naval Ordnance Laboratory subsequent to termination of the war-time work at the Explosives Research Laboratory, Bruceton, Pennsylvania in 1945. Termination of the Bruceton work resulted in moving the impact sensitivity facility to the Naval Ordnance Laboratory. The list is intended to be complete although some omissions may have occurred. Some NOL reports other than impact reports have been included because their subject matter is considered to be relevant to the general field.

A few reports, other than those originating at NOL, are also listed for the purpose of calling attention to the ideas and data which they contain.

- | | |
|----------------------------|---|
| (1) OSRD 6629 | <u>J. M. Downard and R. W. Lawrence</u>
Sensitiveness of High Explosives, 30 March 1946, Confidential (Final report on contract OEMsr-719 with the Hercules Powder Co.). |
| (2) NAVORD Report
66-46 | <u>George F. Strollo</u>
Container Dent Sensitivity of Explosives, 1 April 1946, Confidential. |
| (3) NAVORD Report
85-46 | <u>R. J. Seeger</u>
Final Report on Comparison Test of Impact Sensitivity of Military Explosives, Part I, Summary of Data, 14 August 1946, Confidential. |
| (4) NAVORD Report
94-46 | <u>R. J. Seeger</u>
Final Report on Comparison Test of Impact Sensitivity of Military Explosives, Part II, |

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Discussion of Results, 14 August 1946,
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- (5) NOLM 10,003 E. H. Eyster and L. C. Smith (Naval Ordnance Laboratory Memorandum, White Oak, Maryland)
Studies of the ERL Type 12 Drop-Weight Impact Machine at NOL, 25 January 1949, Confidential.
- (6) NOLM 10,022 E. H. Eyster and L. C. Smith
Gasometric Studies on the NOL Drop-Weight Impact Machine, 16 February 1949, Confidential.
- (7) NAVORD Report 1589 N. D. Mason
Impact Sensitivity Determinations of Explosive Compounds Tested During the Period from 1 January 1950 to 1 November 1950, 1 November 1950, Confidential.
- (8) NAVORD Report 2111 G. Svadeba
Impact Sensitivity of Primary Explosives, 1 June 1951, Confidential.
- (9) NAVORD Report 2140 G. Svadeba
Impact Sensitivity of Perchlorate Explosives, 28 June 1951, Confidential.
- (10) NAVORD Report 2181 G. Svadeba
Impact Sensitivity Determinations of Explosive Compounds Tested During the Period 1 November 1950 to 1 August 1951, 1 August 1951, Confidential.

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O. H. Johnson
Preliminary Studies of the Desensitization
of Explosive Compositions of the Type
Aluminum/Ammonium Perchlorate/RDX,
17 September 1951, Confidential.

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G. Svadeba
Sensitivity of Explosives to Impact; Period
of 1 August 1951 to 1 May 1952, 5 May 1952,
Confidential.

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Russell McGill
The Sensitivity of Explosives, 7 August 1952,
(Translation of a Japanese Impact Sensitivity
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G. Svadeba
Impact Sensitivity of Primary Explosives,
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(15) NAVORD Report
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G. Svadeba
Desensitization of Ammonium Perchlorate
Explosives, 9 April 1953, Confidential.

(16) NAVORD Report
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G. Svadeba
Sensitivity of Explosives to Impact, Period
1 May 1952 to 1 July 1953, 1 July 1953,
Confidential.

(17) NAVORD Report
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G. Svadeba
Factors Affecting the Behavior of Explosives
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D. J. Addonizio and G. Svadeba
Microscopic Analysis of Desensitized Explosives, 29 October 1954, Confidential.
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(Final report for the Naval Ordnance Laboratory)
Kiyo Hattori and W. C. McCrone
Desensitization Studies, 10 June 1955, Confidential (covering the period of contract 15 April 1951 to 15 May 1955).
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E. H. Eyster, L. C. Smith and S. R. Walton
The Sensitivity of Explosives to Pure Shocks, 14 July 1949, Confidential.
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R. H. Stresau and L. E. Starr
Some Studies of the Propagation of Detonation Between Small Confined Explosive Charges, 15 July 1950, Confidential.
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W. E. Dimmock, Jr.

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COMMENT ON SENSITIVITY AND THE USE OF IMPACT MACHINES

D. Price

Statement of Problem and Background

The sensitivity of a material cannot be exactly defined but it is the tendency of the material to show some exothermic reaction under a wide variety of conditions. The reaction may be as mild as a rapidly quenched burning or as violent as a high order detonation. If it can lead to an accident while the material is being handled or used, it must be considered evidence of undesirable sensitivity of the material.

There is apparently no compilation of field accidents in the use and handling of high explosives from which some statistical scale of over-all sensitivity might be compiled. Consequently various investigators have been using a variety of small scale tests to assess "sensitivity" and have been unable to designate any of the numerous ratings obtained as best reflecting the field accidents. Naturally a highly confused and unsatisfactory situation has resulted.

The small scale tests used for sensitivity measurements give a single point value in circumstances where a family of curves should be obtained if the material is to be adequately evaluated. To make this situation clearer, an analogy in the study of metals may be considered. No one now expects to rate metals by measuring the stress necessary to produce one particular value of strain. Instead, the entire stress-strain curve is obtained for each metal, and if two curves happen to cross, a reversal in the rating of the metals at different stress levels is expected. Finally, it is recognized that different rates of stress application result in different stress-strain curves.

The situation in sensitivity evaluation is very comparable. It is believed that the total thermal energy received by the material and the rate at which it is received are the two factors completely determining its tendency to react. Of course, it is more difficult in this case than in the case of metals to determine how much of the energy provided actually goes into the material; that depends on the heat conductivity and capacity of the material itself.

Recently G. B. Cook has integrated the heat conductivity-self heating equation* for boundary conditions to be expected in isothermal baths for five explosives for which the necessary physical values were available. The results demonstrate that for a straightforward application of thermal energy, reversals in rating will occur for ratings carried out at different temperatures. In other words, reversals under different test conditions are to be expected and are confusing only because the entire curve has not been determined.

In the case of propellants, most accidents occur during use of the material as a fuel, i. e., as a result of its exposure to thermal energy. In the case of high explosives, with the exception of cook-off phenomena, most accidents are associated with some type of mechanical impact (dropping a shell, penetration by a bullet, sympathetic detonation). In this latter case, the same factors of total thermal energy and rate at which it is received are still fundamental, but an additional one of the effectiveness of converting the impact energy into thermal energy becomes equally important. Thus the general statement that heat sensitivity and impact sensitivity are unrelated seems incorrect. It seems most probable that the mechanism of initiation is thermal and is the same in both cases, but that physical factors such as hardness of the material affect the conversion of the impact energy into thermal energy so that the rate at which the energy reaches two explosives differ even when the impacts are identical. Thermal tests (vacuum stability at 170°C, cook-off temperature) show tetryl to be more reactive than RDX. Mechanical tests (rifle bullet, booster, impact) show the reverse. This might be explained by the fact that RDX has a Moh hardness of 2.5 while that of tetryl is 0.7.

Impact Machine Test

The mechanical test in widest use (i. e., the easiest and quickest) is the impact machine test. Comparison of test results from one lab with those of another show a chaotic condition, but this test will almost certainly continue to be used for some time as the chief criterion of judging safety in handling. It is, therefore, of some importance to find a way of achieving some agreement in the test results.

*This includes both factors: total thermal energy and rate at which it is received. See G. B. Cook, The Theory of Thermal Explosions, A. R. D. E. Reports 19/55 and 27/55, Oct. 1955.

This test is a single point evaluation, and, therefore, never representative of sensitivities to be expected over a range of conditions. In order to be a satisfactory impact test, the point of evaluation must be so chosen that the test values satisfy two criteria:

- 1) They must be reliably reproducible.
- 2) They must order explosives in a rating equivalent to that which would be found by a statistical evaluation of field accidents due to mechanical impact.

Unfortunately, no statistical evaluation of field accidents is available. However, some well established qualitative information can be used. For instance, TNT has been handled safely for many years, and Explosive D (ammonium picrate) is even less sensitive than TNT as evidenced by the use of picratol (Explosive D/TNT, 52/48) in armor piercing and semi-armor piercing shells. On the other hand, RDX is so sensitive to mechanical impact that it cannot be used alone. It is used only in combination with less sensitive materials such as TNT or wax. Other qualitative information of this type is available, but the present examples serve to show that a useful impact test must rate these materials in the order of RDX, TNT, Explosive D for decreasing sensitivity. Unless an impact test rating is in agreement with the available handling information, its test values should never be considered as sensitivity ratings of the explosive.

The difference in sensitivity ratings from laboratory to laboratory arises, of course, from using test values obtained at different evaluation points as sensitivity ratings. Different tool types are used in different machines and tool types similar to No. 5 (which does not satisfy criterion 2) are quite prevalent. While there is general agreement that the 50% explosion level is easiest to measure, there is some opinion favoring the use of the 10% level in a safety evaluation.

The purpose of the work reproduced in this NAVORD Report was to develop a set of tools by use of which impact test values satisfying the two criteria of a useful impact test could be obtained. It is reproduced here so that other investigators may profit by it, and not need to retrace the initial development work. By the end of his investigation, Davis had found that, of the tools tested, type 12 best satisfied the criteria for most solid high explosives, and type 3 was [REDACTED] primary explosives and very sensitive high explosives.

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He recommended type 123 tools for liquid high explosives and the discarding of the other types of tools studied for reasons noted in the reports. Why Eyster and Davis subsequently recommended (OSRD 5744) testing with tool types 33, 5, and 12 is not clear. The same data were considered in both cases and the data (those reported here) indicate that type 5 tools resulted in values which satisfied neither of the test criteria.

The present data indicate that ratings at the 50% level were generally the same as ratings at the 10% level if the type 12 tools, 2.5 kg. weight and 35 mg standard sample size and preparation were used. The same rating at two different levels would not necessarily be expected for any general test. It must also be kept in mind that the impact test gives a statistical evaluation and is, therefore, subject to the limitations of any statistical study. In particular, one cannot expect to obtain significant values for the lower levels with a statistical sample size of only 25-100 shots.

If No. 12 tools (or a better design) should be established, there is still some control work that should be carried out on this test. It consists of investigating the effect on test values of

1. Organic material. ((sandpaper and its adhesive)
2. Other weights than the 2.5 Kg one now used
3. Temperature variation
4. Physical state of sample
 - (a) Use of pressed and cast pellets rather than powder.
 - (b) Pressed pellets preferable for comparison of high explosive test values with those of propellants.

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